CO-OPERATIVE RESEARCH IN INDUSTRY

by

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"*That our garners may be full and plenteous with all manner of store: that our sheep may bring forth thousands and ten thousands in our streets*

"*That our oxen may be strong to labour, that there be no decay: no leading into captivity, and no complaining in our streets.*"

PSALM: 144 v.13–14.

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FOREWORD

THE RESULTS OF research are not always so obvious as they have been during the recent war years but they have nevertheless a habit of infiltrating insidiously into the framework of life. A single new idea is introduced here, a slight improvement there and suddenly we find the whole structure changed. Our present life is largely conditioned by the results of research of which most of us are ignorant

Co-operative research is a tool that has been quietly fashioned during the last quarter of a century and that is now likely to prove one of the sharpest we have for the future. The need for scientific research is such that men, materials and money on the scale required are all lacking The one thing that is available is a form of organization that enables us to use each to the best advantage. The atomic bomb, radar, penicillin, fog dispersal and many other triumphs of wartime research were brought to swift success by national and international co-operation.

The co-operative research organizations in Great Britain played a substantial part in the war effort but it is not the function of this book to describe their contributions to camouflage, flame-throwing, rectification of bomb damage, Service clothing, tropic proofing, assault craft or the thousand and one problems that called for the swift solutions made possible only by co-operative effort Some day perhaps that story will be written but for the present the reader must take it on trust.

This book sets out to describe what co-operative research is, how it is now organized and in what way it may contribute to the solution of some of the pressing problems confronting us These pages attempt to bring together the principles of co-operative research learned since the first world war and it is hoped that by so doing they may prove a slight contribution to the central problem of assuring a lasting peace, to which science can offer at least as much as it did to total war.

I am indebted to many kind friends in this country and abroad for information and criticism. In particular, I am grateful to the Department of Scientific and Industrial Research for permission to reproduce the picture of the National Physical Laboratory, to Dr. F. C. Toy for the photograph of the Shirley Institute and to Dr. W. A. Hamor, Associate Director of the Mellon Institute for the excellent photograph of, and for much valuable information concerning, that institution.

D. W. H.

Dec. 1946

I

THE IMPERATIVE OF RESEARCH

THE PROSECUTION OF scientific research on a large scale is a prominent feature of modern development. Universities and technical colleges insist upon research productivity from their scientific departments; the State spends large sums annually upon it; industry has developed it into a masterly weapon; the creation of special research institutions and the furtherance by various means of particular lines of enquiry are noticeably on the increase. What lies behind this rapid development and how best can it be brought into relation with the necessities of the times?

The Intellectual Stimulus of Research

Research work as a whole, when carried out on the scale to which we have now become accustomed, has repercussions on life that permeate to every individual and influence the most diverse circumstances. The presence in the community of a large body of individuals whose time and energies are spent in the elucidation or application of new knowledge, exercises a subtle and all-pervading intellectual stimulus that can hardly be assessed but which none the less affects the outlook and perspective of us all. This research atmosphere, attenuated though it may be by the time it reaches the average man, induces a sense of well-being in the whole community, as does all scholarship and intellectual activity, satisfying to the body politic the same urges as the kicks and stretches of the growing infant. It is the evidence of growth and the outward manifestation of vigorous energy.

By no means all of the research now being carried on is directly related to present needs and there are some that argue that to attempt to link research with immediate necessities will destroy its nature. Generally speaking, however, there is no longer any sense that research work conditioned by circumstances requires justification All research whether or not related to an explicit or immediate application to our needs should be encouraged as an intrinsically desirable thing

It was research untrammelled by any conditions other than the intense curiosity of the researchers and the desire to extend information that first flourished, and by which much of the major knowledge of the universe was revealed. Newton, when he laid the basis of physics in the laws of motion that he enunciated, was presumably not actuated by any desire other than that of adding to and disseminating the sum total of human knowledge, and the same might be said of the majority of great discoverers of the past, who by their contributions have enormously enriched the intellectual life of the whole world.

Material Influences of Research

This freedom of outlook did not prevent the discovery of large stores of useful knowledge. The greater part of the material advancement of our times has been based upon work carried out with no object other than the quest for knowledge, and this is important, for social progress goes hand in hand with material well-being. The dissemination of news and views through the radio, the press, and books depends upon the material advances that have brought these methods of broadcasting to their present perfection. The leisure to appreciate good writing, good music, good drama is the result of material advances that have taken the burden of labour off the shoulders of the individual and thrust it upon the machine. The time to learn even to read and write is of comparatively recent origin, and the comfort of body resulting from comfortable homes, good food and warm clothing which alone make it possible to appreciate the good things of life, has its origin in material advances based upon research. There is much still to be done, but the days of the tallow candle and manuscript when only the wealthy dilettante or the poor professional scholar could enjoy intellectual pursuits has passed. The gates of learning and appreciation are now open to all, not so much because of an extension of the intellectual field as because of the more favourable material circumstances provided by research

These material benefits, in so far as they affect the majority, arise from the applications of research by industry. It is modern industry that is responsible for modern amenities and industry lies, therefore, at the bedrock of our social development. There is scarcely a feature of time-saving, labour-saving, comfort-ensuring amenities that cannot be attributed to industry. Our health and the increased expectation of life result from the wholesale production by industry of products that enable the latest ideas in medical and social science to be translated into actualities. They range from main drainage and sewage schemes to hypodermic needles of the finest gauge and quality, from machinery that decreases occupational disease to contact lenses for defective sight, and to new and powerful pharmaceuticals such as vitamins, hormones and antibiotics.

Every aspect of life is governed by industrial progress. The clothes we wear, the food we eat, the houses in which we live, the streets we walk along, the ships, trains, cars or aeroplanes in which we travel, the communications we have with one another over vast distances by wireless, telephone, telegraph or cable, the books we read, the recreations in which we indulge, all are the manifestations of industry's vast influence on our social environment. To how many of us does it occur that cleanliness itself is of comparatively recent origin and is both the basis of, and springs from, one of our great industries? If cleanliness is next to godliness then material well-being is undoubtedly the parent of social advancement.

The common amenities of to-day were only a short time ago the prerogatives of the wealthy few, and it is industry that has brought about the change and that must provide increasingly in the future, the leisure for all that will permit the acceptance by all of gracious living. The material benefits accruing from research are therefore of comparable importance to the intellectual transfusion that is constantly being effected in a group where it flourishes.

Industry alone, however, could not accomplish this transformation. Industry is as old as man himself and, until recent years, it has meant always the subservience of the mass of mankind to the tasks to be performed It is the avid pursuit and exploitation of new knowledge that has placed the powerful industrial tool in our hands to destroy poverty and the drudgery of labour This pursuit of new knowledge started relatively recently, but it is a snowball which has accumulated an increasing mass and an increasing momentum as it has progressed. It is dependent on research and development which has itself now reached the scale of an industry.

The provision of amenities on a scale sufficient to bring them to every individual is valueless unless, at the same time, they come within the reach of all. This may be done in two ways, either by reducing their cost or by increasing the real incomes of the population Industry has done both. By taking advantage of new knowledge it has cheapened the production of goods and materials and, by the labour it has employed to cope with increased production, it has provided both directly in wages and indirectly, in revenue to the State, the wherewithal for the purchase of the goods produced. At one and the same time, therefore, research makes it possible, through industry, to provide the goods and the wherewithal to obtain them.

Any attempt to raise the standard of living in Great Britain or any other country must ultimately depend upon research The rate of improvement of material comforts that has become commonplace in this century can be, and almost certainly will be, accelerated in the post-war years by the application of new knowledge and technical skill which will also produce and distribute the necessary wealth to enjoy them. Social advances do not arise from simple legislative procedure or financial outlay. It is not enough to say that we will now improve such and such a situation or we will now produce such and such a desirable service or commodity. It is first necessary that the knowledge shall be available of how to implement the decision The change from the England of Queen Elizabeth to the England of to-day springs from the knowledge hardly wrought by research.

There may be some who feel that Merrie England is preferable to modern England and who would, therefore, be disposed to blame rather than praise the extension of knowledge. It is inevitable that scientific research may sometimes produce social problems as well as social advances. It is obvious, for example, that the provision of one desirable

product more cheaply or more attractively than another, may result in the virtual extinction of an industry that depended on the more expensive or less attractive article. Such events have been used, and no doubt will be again, as an argument that research is a bad thing.

The disturbances that introduced the industrial age are common knowledge, but it is equally common knowledge that Britain's prosperity dates from that introduction. So it must always be. In transport, the railway displaced the stage coach, and ostlers, innkeepers, drivers, coach-makers saw the end of their employment in sight; but in return the railways employed guards, signalmen, drivers, firemen, porters, plate layers, engineers, steel workers and a host of others until the number of employees on the British railways before the war had reached the figure of about 600,000 with an annual salary bill of £105 million. Steam displaced sails and steel displaced wood on the seven seas and so craftsmen saw their livelihood slipping from them. But steam and steel made possible the great shipping and allied industries in which hundreds of thousands find employment in shipbuilding yards, as merchant seamen, as stevedores, warehousemen, packers and all associated activities related to the great business of shipping. The developments of the internal combustion engine now offer severe competition to the new-old methods of transport, but they themselves provide newer vast industries giving employment to thousands for the production of petroleum, aluminium, rubber, cars, heavy road vehicles, aeroplanes, speed-boats, diesel engines and so on.

Opportunities for Employment

The employment, wages and salary bills, the return to investors and the consequent direct and indirect increase in the national revenue provided by industries built upon, or largely dependent upon, research is little short of staggering. According to the Fifth Census of Production 1935, the electrical industry then employed almost 250,000 persons with a salary bill of £16 million; the motor and cycle industry employed 225,000 and paid salaries amounting to £25 million; aircraft occupied 35,000 and paid them £4 million; chemicals, dyestuffs and drugs employed 75,600 and paid out £6½ million. This list, which could be extended into plastics, rayon, rubber and synthetic rubber, petroleum and its products, gives some idea of the material resources provided by the industries built upon scientific research and also of the return in the distribution of wealth they afford.

The benefits do not stop at the direct employment and direct wages provided. Many thousands of persons were indirectly employed to provide services and raw materials to meet their needs. They consumed, for example, coal, coke, fuel and lubricating oil, electricity, iron and steel, non-ferrous metals, paper and other commodities as well as services such as transport by road, rail and sea to distribute their products, banking, and national and international postal services. All these

auxiliaries to production provided in turn employment on a scale undreamt of and impossible but for the demands of industry built on research.

The primary industry of all countries is, or was, agriculture and the new knowledge provided by technical advances has resulted in the decline of agriculture as a field for employment. The proportion of the population engaged in agriculture and similar primary production invariably falls as countries improve their economic situation. The improvement is always the result of research and development which normally takes the line of industrialization to produce wealthy industrial countries such as the United States of America, Great Britain and Germany but may also result in increased output per head in the primary industries as in Australia and Canada. Agriculture, when practised by the majority, is poorly paid work in which the hours of labour leave no leisure and the rewards provide no opportunity for high standards of living. New knowledge, which draws men from the fields to more remunerative labour, can also be applied to the fields themselves to allow those that remain to produce more per head to meet the needs of the now absent consumers, who in turn can pay more for the labour that feeds them. So, for the first time in history, a minimum wage for farm labourers has recently been established and, if scientific knowledge is used on a sufficient scale, the labourers can be worthy of their hire and the farms, in spite of the increased charges, can be made to pay.

Between 1881 and 1931 the number of persons in Great Britain employed in the manufacture of chemicals, paints, oils, rubber, etc.—all industries dependent on technical knowledge—increased by about 250 per cent. and in the manufacture of metals, machines, implements and conveyances by about 57 per cent The United States census records show that between 1920 and 1930 there was a percentage increase in the number employed in the chemical and allied industries of 66 8, in fruit and vegetable canning of 83·7, in electrical machinery and supply factories of 80·9, in automobiles of 33·7.[1] These are the industries which in the same period have been spending time and money on large scale research and it is not fanciful to trace the expansion of earning power that they have created to their encouragement of research.

It cannot be denied that the extension and exploitation of research by industry is a sure means of increasing employment. The improvement of existing industries and the creation of new ones, whatever temporary and apparent ill effects they may have, must, in the long run, improve the possibilities of employment. The lack of research spells stagnation and the loss of all opportunity for gainful employment. It may well be that the ultimate decision before the country is whether to spend money on doles or research with the corollary that while the

[1] A G B Fisher *Some Essential Factors in the Evolution of International Trade.* Manchester Statistical Society. March, 1943.

latter is self-perpetuating the former may finally reach a point where the national income will fall below the unemployment payments to be made.

Conditions of Employment

It is not only the opportunities for gainful employment that are improved by research but also the conditions of employment. The recognition of the part played by industrial fatigue in the loss of efficiency and the proneness to accident is the outcome of intensive long term research and has resulted, and will do so still more, in the amelioration of the conditions of employment. Improved and more efficient production means shorter hours of work for the same or even greater output. The era of the twelve hour day has passed and is likely soon to be followed by the general adoption of the five-day week.

The recognition of the causes of industrial diseases, leading in the first place to legislation for recognized compensation for loss of health, and ultimately to their eradication, is the product of painstaking, persistently pursued research work. The dangers of silicosis have not only been recognized and statutory provision made for its victims but patient investigation has led to possible amelioration by such methods as stone-dusting. The recognition of mule spinners' cancer as an industrial disease was followed by an enquiry into its cause leading to tests for safety of the lubricating oil used to ensure its freedom from dangerous qualities. The admission of byssinosis as an industrial hazard was followed by an intensive examination of the part played by the dust in the card rooms of spinning mills. The susceptibility of painters and others to lead poisoning has led to the introduction of titanium oxide as a substitute white pigment which can be used with safety. Dermatoses of all sorts, one of the most prevalent forms of industrial hazard, are the subject of active research work and much has been done to understand their causes and to eliminate or ameliorate harmful materials. The introduction of new industries, new methods, and new materials may at any time be fraught with the possibility of industrial disease and it is scientific and medical research that will protect the worker and the community from the besetting dangers.

Research as a Balance Wheel

The dangers of research in one industry to the employees working in other industries has been mentioned Fluctuations of the employment opportunities may be a source of real concern to all whose livelihood is dependent upon healthy industry. But the danger is not dependent upon research alone. Political differences, the loss of raw materials, industrial unrest, economic uncertainty all offer potential rocks upon which the individual's ship of employment may be wrecked beyond salvage. In the same way, circumstances over which the individual has no control may produce a demand for labour that cannot be

met and this, although possibly to the individual's advantage, is as much a national danger as under-employment in that full advantage cannot be taken of the flowing tide. In all these circumstances research allied to enterprising industry provides a balancing factor that will maintain a steady and not easily deflected advance. In the event of a shortage of labour to meet increasing demands, the wholesale application of research will reduce the labour required to maintain production. In the event of under-employment research applied vigorously by determined industry will find new products to absorb the idle labour

The value of research as a national balance wheel is particularly important at a time like the present when the future requirements are especially obscure. It is confidently expected that there will be a boom period after the war. This was the experience in the first world war after which there was very little unemployment for the first year and a half. After the recent war there remain all the shortages of war-time austerity to be made up. Industrial replacements that have been neglected, repairs and refurnishings impossible during the war, to be put in hand, consumer goods stocks to be replenished, new building and the supply to foreign countries suffering equally with Great Britain the rigours of an intensive war-potential, will all make for a high demand for production. In this circumstance research will no doubt be called upon to assist industry to meet the problem of production. But the aftermath of the 1914–1918 war contains a warning as well as an encouragement The percentage unemployment among insured workers in April, 1920, was 2 8 per cent. By March, 1921, the figure had risen to 15 4 per cent. When the decline in employment set in it was sudden and rapid A similar circumstance must be prevented after the 1939–1945 war by intensive unremitting research. The satisfaction of shortage demands and the return to normal demand will of necessity throw the labour market into confusion unless, in the meantime, new products creating new demands have been made available.

Economic security by the provision and maintenance of employment and by financial gain is not the end of the story, for the diversification of interests that research makes possible leads also to stability. A country, a district, even an individual firm whose interests have been spread by research, developed out of research and are maintained by constant research, though it may pass through periods of depression in common with other units, can never face the utter disaster that may befall the single interest unit developed usually on preliminary natural advantages that needed little research for their exploitation and which are typified to-day in the United Kingdom by the economically vulnerable areas of Tyneside, South Wales and Lancashire, in the United States by the cotton belt of the South and the farm lands of the Middle West, and by the cotton and coffee growers of Brazil Financial ability and financial stability go hand in hand with the development of industrial research.

Research and Exports

The advantages accruing from large scale research work to an internal industry can also be enjoyed by an export industry. One of the strongest reasons for an intensified industrial research programme in Great Britain is therefore to be found in the foreign trade position. In the inter-war period she imported goods to the average annual value of £900 million, made up of £400 million for foodstuffs, £250 million for raw materials and £250 million for manufactured or semi-manufactured products. Without a substantial export programme it is impossible to import on this scale and without the imports the standard of living of 48 million people in the British Isles must decline and their industrial activity diminish for lack of raw materials. A strong export position is therefore to Great Britain not a political luxury but a vital necessity. Without it the country cannot carry on. It is one of the major tasks of British industry to maintain the import standard by providing in the shape of manufactured exports the wherewithal to purchase abroad.

The average annual British visible exports during the inter-war period amounted to £500 million, leaving £400 million worth of imports to be paid for by so-called 'invisible exports'—shipping income, overseas investment income and receipts from short loan interest and commissions. The following table shows the relation of visible exports to retained imports in the years 1928 and 1938 and illustrates our dependence upon invisible exports.

U.K. Overseas Trade 1928 *and* 1938 (*£ million*)

	1928		1938	
	Retained Imports	*Exports*	*Retained Imports*	*Exports*
British Dominion (excl. Eire)	192	176	215	139
Rest of Empire	100	152	123	96
U.S.A.	178	47	112	20
Europe (excl. U.S.S.R.)	384	198	252	137
Rest of World	221	151	156	79
Total	1075	724	858	471

It will be observed that both imports and exports fell off considerably from 1928 to 1938, the exports to a greater extent, so that although imports had been reduced from £1,075 million in 1928 to £858 million in 1938 our dependence upon invisible exports had actually increased from £351 million to £387 million and the proportion of imports paid for by invisible exports had risen from 33 per cent. in 1928 to 45 per cent. in 1938.

These figures are important because the impact of war has changed

Great Britain's position very materially. In order to pay for necessary war supplies we have disposed of some £1,000 million of long term foreign securities mostly in Canada, U.S.A. and India and have indulged in short term borrowing mostly in Canada and especially India to an amount of about £2,000 million. The possibility that Great Britain might become a debtor nation is not now a serious one, but it is apparent that our income from invisible exports will be greatly decreased, probably to not more than one half of what it was before the war.

This position will be aggravated by the relative change in the strengths of the British and United States merchant fleets. It was British policy during the war to concentrate on naval building while the U S.A. has emerged from the war with the greatest mercantile tonnage in the world. A similar trend occurred during the last war but British shipowners were able then in a relatively short time to recover their lost position Whether this will be repeated is a matter for conjecture.

Paying for Imports

Simple arithmetic dictates that if the same value of imports is to be enjoyed after the war as was normal before it, there will have to be an increase in visible exports of some £200 million or about a 40 per cent. increase on pre-war. An increase of such dimensions will not be easy. Another effect of the war has been to encourage the industrialization of our foreign customers. Examples could be given without stint. South America is reported to have increased the output of cotton goods to a point where the loss of both U.K and Japanese imports has been completely offset Canada, since the war began, has become the greatest base-metal exporter in the world,[1] and steel production has doubled since 1940, so that she is now the fourth among the producing nations. In India, Canada and Australia the production of chemicals has greatly increased The industrialization of these countries was on the way but the war has speeded it up, and has thereby faced Great Britain with a problem that must be solved as rapidly as these countries have progressed.

Furthermore it is likely that our terms of trade will be less favourable than heretofore. The laws of supply and demand are not changed by the changes in financial ability of a few of the customers except insofar as they reduce demand and thereby reduce the cost It is always true that goods in short supply and high demand at the same time will command a high price. Great Britain was fortunate in that, being first in the field of industrialization her manufactured products commanded high prices relative to the cost of the primary products, food and raw materials that she wished to buy. The rapid spread of industrialization has increased, and will increase still further, the supply of manufactured goods A proportionate decrease in value will result. At the same time, the major nations are increasingly occupied with nutritional problems and have become aware of the value of foodstuffs.

[1]Report of Dept. of Munitions & Supply, 1943

Food imports, which have always been of importance to Great Britain, have now become a part of national policy-making and their importance to our national well-being has thus been heavily underlined. We must expect therefore a change in the value-rates between raw materials and foodstuffs on the one hand, and manufactured goods on the other, altogether to the disadvantage of the latter.

To maintain our visible exports at their pre-war value will not therefore be sufficient. For the same imports we shall have to pay more than hitherto, for raw materials and foods will command higher prices. For the same price we shall receive less than we have become accustomed to, with a consequent decrease in the standard of living. The sterling balances held abroad will not ease this situation although the engineering industries may benefit for a time from this since mechanical and transportation products will be in high demand for the further industrialization of our former customers.

It is the task of industry to maintain and, if possible, increase the level of exports so that the level of imports can also be maintained. The only importance of exports is their value relative to imports. A credit balance of payments which was the ambition of the bankers in the 1920's has been exploded as a reliable guide to policy in the international field. It is useless, and worse than useless, to collect money that has no value or goods that are unwanted. But for necessary imports, exports must be found. Under any competitive system an industry can only exist, provided it can supply what the customer wants at a price the customer can afford. All kinds of subterfuges to attain this end have been adopted by countries that wished to export and that wished to maintain local industries running inefficiently compared with foreign competitors. The chief method perhaps has been the widespread use of subsidies, open or concealed, to enable industries to supply abroad at less than the economic price. In some cases, notably the Lancashire cotton industry, where no subsidy was available, the industry steadily drained away its life blood by weak selling to keep markets in standard lines. The hope of a restoration of trade during which losses could be recouped, upon which such a policy was based, was destined never to materialize.

The Need for Efficiency

Thirty-five years ago Robert Kennedy Duncan, the founder of the highly successful Industrial Fellowship Scheme, pointed out that business intrigue had nothing more to learn and that the era of an expanding and not too particular population in America had gone [1] In efficiency of production alone lay the way to safety It was on this thesis that he built his structure of industrial research which is discussed later.[2] What he said of America then has been increasingly true of the rest of the

[1] Journal of Society of Chemical Industry, 1909, vol. XXVIII, p. 684.

[2] *See* Chapter VI.

world ever since. Weak selling at marginal profits or no profits at all is the path to ruin. Bolstering by tariffs may afford a temporary safeguard but at best this is, in a great importing country, protection at the expense of fellow countrymen and at worst a rapidly exhausting tuberculosis of the industrial system that cannot possibly continue for long. In fact the main, and almost the only, value of tariffs is to show where the weakness lies and therefore where the most drastic remedial measures of increased efficiency must be applied

Business, Industry and Technology

In view of the limited range of Great Britain's raw materials, of her reliance on staple industries for export revenue, and of the impossibility of devising new and more ingenious business methods to support declining industries, it is, on the face of it, difficult to see from where the necessary increased exports are to come. The business men of the United Kingdom are as good as ever and not inferior to those of other countries but this is no longer the task of business It has become the task, the gigantic task, of industry. It has become a matter of technology. The efficiency of production and the value of products must be increasingly raised. Mere increase in volume, which could be obtained by giving away the products of industry, is no longer sufficient. From now on, it is the value of exports that must be raised: an increased value perhaps of a smaller volume.

To accomplish this means a switch from low grade to high grade goods for export markets. Great Britain has been too long dependent for her exports on industries that are supreme in no market There has been a slow change going on already in favour of higher grade exports as the following table shows. Coal, iron and steel, and textiles, have declined while machinery and metals have increased since before the 1914–1918 war.

Change in Composition of Exports from 1913 to 1937

	(*Percentage of total exports*)	
	1913	1937
Coal, Coke etc.	10 2	8·0
Cotton yarns & manufactures	24·2	13 1
Ships & boats	2 1	0·8
Metal & Engineering groups	27 2	33 8

In 1913, our greatest single exporting industry was cotton and the decrease shown in the table represents a decline in purchasing power of £60 million per annum. The trend towards higher value exports has been, however, too slow and must be accelerated immeasurably in the next few years.

We must have an increased export as a matter of necessity and this increase must be one of absolute value and not merely of quantity. In other words, we have reached a point where mere expansion of the staple industries, even if that were possible, is not sufficient. From now on we must, as we did a century ago, export products for which our customers will willingly pay high prices. Considering the limited range of our natural raw materials there can be only one answer to this challenge. New industries must be built upon our meagre resources, and the staple industries must be revivified to produce with greater efficiency a wide range of new and desirable products.

From now on we must export products with a high content of skilled labour. We need to export brainpower. The goods for which our overseas customers will pay high prices are those in the invention of which a high quality of brain work has been expended. The only industries, which will be expandable after the war are the research industries, and this country's future prosperity depends on its pre-eminence in the already known research industries and in the discovery and development of new industries. In a word research, allied to enterprising industry, holds the key to export prosperity which is in turn the only ground upon which the living standards of a population of 48 million can be maintained in these islands.

Whether we like it or not it is apparent that research has come to stay We cannot stop the wheel which is now turning faster and faster every day. There will always be enquiring minds which will constantly be examining in ever closer detail the bases of our life. Industry in its turn will take up and use the knowledge so revealed, not alone in this country but in all countries where knowledge is encouraged and research flourishes Progressive countries will take advantage of this everflowing spring to their continued advancement and the happiness and prosperity of their peoples It behoves us, therefore, to examine how best we may exploit the natural genius of our inventive and imaginative minds to the benefit of the whole community.

II

THE ORGANIZATION OF RESEARCH

INDUSTRIAL PROGRESS IN the past was dependent largely on the intuition, genius or experience of individuals who, conversant with the problems facing them, devised, sometimes by brilliant master-strokes, sometimes by plodding trial and error, methods to overcome them. In all proba-

bility many of the older industries arose almost by accident. Men more observant than their fellows noticed the changes that occurred in nature and set out to produce them deliberately. The fused products sometimes found in the ashes of fires, no doubt led some individual to light fires for the express purpose of producing fused material and so, perhaps, came the smelting industry. Charles Lamb's Essay on Roast Pig gives a picture of how simple industries may have arisen. It shows also that so long as men confined themselves to observation and imitation and failed to proceed to intelligent deduction and experimentation, the methods by which they were able to attain their ends were likely to be clumsy and costly—so clumsy and so costly that while they could provide something more than had been known before, they could not provide sufficient of the new product to exercise any marked effect except over very long periods. The lessons learned were slow and the production infinitesimal so that we now talk of ages—the Stone Age, the Bronze Age, the Iron Age.

The Experimental Method

By observation and imitation men were able to adapt to their own use some of the principles and raw materials found in nature. It was Roger Bacon who first expressed the need for the experimental approach, but it was not until Francis Bacon, three hundred years later, that the experimental method was developed into a tool that could be used to the rapid expansion of knowledge. With its introduction came a speeding up in the development of knowledge and its application to industrial processes. Modern industry may, in fact, be said to date from the second Bacon. Even so, the new experimental method was for a long time confined to individuals. Exceptionally gifted men in Great Britain like Black, Watt, Faraday, Kelvin, Bessemer, Cavendish, Dalton, pursued an experimental career and left behind them the knowledge which has transformed our mode of life and which is the foundation upon which the industrial structure rests. Beside these outstanding men there must have been countless others, whose names have not come down to us, associated with great or dramatic discoveries, who contributed greatly to the superstructure raised upon their foundations

First Steps in Industrial Research

Before the end of the nineteenth century industry had begun to recognize the influence of the experimental method and particularly of the progress in the sciences made with its aid. Scientific men attached to the Universities were sometimes called into consultation to help to solve problems that were confronting rapidly expanding industries. Much of the experimentation that occurred was not directed in the first place to the founding or assistance of industry It was in a sense fortuitous that so much of the knowledge that was laid bare was useful to industry, and this tenuous link between experimentation and full scale production could not long suffice

New industries were already in existence which owed their very life to scientific discovery and their only hope of continuance lay in the constant application of the experimental approach. These industries, therefore, took into their employ a few scientists for the express purpose of solving *ad hoc* problems and later of providing a basis of further knowledge upon which extension of the industries could be based. It was a short step to organize and equip laboratories in which these men could work and before the end of the century industrial research laboratories were a recognized, if still small, part of the industrial organization. The objects of these laboratories were mainly the prevention and utilization of waste, the standardization of products and processes, the reduction of costs and the introduction of new products or methods within the particular limited field covered by one industry or even by one firm. The first step had been taken in the organization of research.

The New Universities

At the same time as industry was finding it necessary to establish laboratories in which the researchers could concentrate their efforts for its benefit, it was also discovering that the demand for men trained in the new sphere of activity greatly exceeded the supply. The universities of Oxford and Cambridge were not yet prepared to recognize the new subjects, Durham was following their example and London was far removed from the site of the great industrial expansion. The industrial centres of England needed technical experts and educational institutions in which science and technology predominated sprang up to meet the need. Owen's College, Manchester, founded in 1851, was the first and was followed in quick succession, after a preliminary pause of some twenty years as though the Manchester experiment were being weighed in the balance of time, by the Yorkshire College at Leeds, University College, Bristol, Mason College, Birmingham, University College, Liverpool and University College, Sheffield.

So adequately did these institutions meet the needs of the times and so broadly based were they that university status could not reasonably be withheld from them. Their phenomenal growth to maturity resulted in the establishment first of the Victoria University of Manchester in 1880. Both the Leeds and Liverpool colleges were affiliated with this institution but were separately organized as independent universities in 1903 and 1904. Mason College became the University of Birmingham in 1900, University College, Sheffield, became a university in 1905 and University College, Bristol, in 1909. The irresistible force that propelled them from obscure local colleges to national, if somewhat localized, universities was the interest they took in the sciences and the provision they made for scientific research.[1]

[1]University College, Reading, founded in 1892 with a rather different background did not achieve university status until 1926 and has remained a small institution compared with those named.

Pure and Applied Research

Up to this time scientific research had been largely unorganized. Advances were made on the basis of the inventions of individuals but inventions were beginning to exert a declining influence. Haphazard discovery had to give way to organized search. The period of invention gave place to the period of science. With the organization of industrial laboratories on the one hand and the development of university laboratories on the other, a distinction was drawn between applied and pure research. The distinction so drawn is often enough without a difference. It implies essentially a difference in motive which is at all times difficult to assess. Broadly speaking, however, pure, or as it is sometimes called, academic, research is undertaken with no further intention than the extension of natural knowledge. There is no specific intention that the knowledge so achieved shall be of the kind that we term useful. Nevertheless it often is, or becomes in time, of the first importance to the community or even to a specific industrial process

We have already referred to the great experimentalists of the past who, working without the assistance now afforded by the extensive financial and material facilities of modern laboratories, laid the foundations in the extension of pure science for the establishment of whole industries It is not possible now to say for certain by what motives they were actuated, but it is reasonable to suppose since they received so little encouragement that they merely sought to increase the sum of human knowledge. So to-day all research may be of value to industry in the near or distant future and nobody can say that this or that piece of research is of no utilitarian value. On the other hand, applied or industrial research is normally undertaken with the avowed object of benefiting industry. Just, however, as there is no specific intention of benefiting industry in pure research so, in the applied variety, there can be often enough no guarantee that the research will be of immediate value.

Pure and applied research may in fact be indistinguishable by any criterion. Although pure research is normally considered to be the prerogative of academic institutions some of the outstanding pure research of modern times has been carried out in industrial laboratories Dr. C. J. Davisson of the Bell Telephone Company laboratories in New York and Professor G P. Thomson of the Imperial College, shared a Nobel Prize in 1937 for work carried out independently on the conception of electrons in wave packets The work of Carruthers on high polymers in the laboratories of the Du Pont Company, which resulted in the production of nylon; or of Langmuir at the General Electric Company, or the research in the laboratories of Imperial Chemical Industries which led to the production of the methacrylate resins, best known as Perspex, were as fundamental in character as any pure research. At the same time some applied research is carried out in academic institutions, either independently or at the instigation of the great industrial concerns, and

much of the applied research whether carried on in academic or industrial laboratories involves scientific work of as high a quality as pure research

Between avowedly pure research and avowedly applied research there exists all shades of gradation, and it is often impossible to distinguish the one from the other. The pure scientist in an academic institution may, if he is a metallurgist, be interested in the production of alloys solely as a mental exercise or for the elucidation of general principles that can be passed on to students, and in his studies he may make an exhaustive examination of the alloys of different metals, cataloguing their properties and recording their behaviour An applied scientist working in the laboratories of an industrial concern may carry out precisely the same investigation with the avowed object of selecting those combinations which may prove of value to his firm A chemist or a pharmacologist may carry out a long investigation on the production of new drugs with specific actions, either to establish principles relating to the activity of drugs or to introduce new therapeutics, and usually such work will, wherever or by whomever it is carried on, be a combination of the two objects since the most academically-minded can hardly be oblivious to the possibilities for good of the introduction of a new and powerful drug, nor can the most industrially-minded be blind to the need for establishing principles of guidance

Applied Research and Development

This sub-division of the early stages of organized research into industrial and academic, pure and applied, was too simple to withstand for long the increasing complexities of research needs. It became necessary to draw the more subtle distinction between applied research and development. In the latter case it is assumed that the raw knowledge has already been laid bare and has already been assessed as of value. It is essential now, to select, to extend, to apply, to exploit just those aspects or sections of it which show most promise of usefulness. To return to the illustrations above: after the metallurgist has made his wide survey and completed his catalogue, one or more of the alloys produced may show exceptional promise in a specific direction. These particular products will then be studied further, will be converted to the purpose in mind and their behaviour in use carefully considered; their production on a large and economic scale will be examined, they will be compared with present materials already serving the purpose or, if a new purpose is envisaged, its advantages will be estimated until finally the point can be reached when a decision is taken to put the product on the market. It has been developed to a commercial proposition. Similarly, out of a wide range of related drugs, one may be selected for development on a commercial scale. Generally speaking, it will be apparent that the originality of thought is completed with the research, though even this is a dangerous assumption since the development may give rise to unforeseen and unexpected

difficulties that will necessitate genuine original work before the development can be successfully completed

Research—A New Industry

Although the organized prosecution of research began in the last century, it was not until the first world war showed up the deficiencies of research in this country that it began to be practised on a large scale. In the last twenty-five years, research has become an industry on its own—a small and specialized industry but like so many other small industries, a key one. Compared with the industries it serves, research is a recent innovation and in its short history it has largely been engaged in catching up not only with the knowledge and experience already available to industry, but with methods of organization to give it the same efficiency in its conduct that industry already possesses. The pioneer work has now largely been completed and procedures for the conduct of research in most circumstances are reasonably well established though new and improved techniques will unquestionably be evolved, for there is no indication of any slackening in the impetus of discovery, and industrial research laboratories are likely to grow in number, size and diversity of the fields covered.

It is now necessary before embarking upon research expenditure, to make a conscious effort to study the needs and the organization best suited to meet them. Well organized and carefully planned research laboratories are powerful tools to achieve the technical ends necessary to successful industry. The last twenty-five years has seen the introduction of new concepts of research organization and because of the potential value of well-established laboratories and the corresponding risks of poorly-established ones it is important to know how to get the maximum results economically.

Convergent and Divergent Laboratories

The first step in the understanding of the new complex set-up for research organizations was taken by C E. K. Mees, in 1920[1] in distinguishing between what he called 'convergent' and 'divergent' laboratories. Research institutions of the former type concentrate upon a group of related problems while in institutions of the latter type work upon problems of many different and unrelated kinds may be carried on.

The early university laboratories were divergent in character, but in time eminent professors gathered around them large groups of students who were trained in research methods by assisting the professor in elucidating problems in a particular field which he made peculiarly his own So schools of research of a convergent type grew into existence. Many outstanding examples of this kind of growth may be cited—the pre-occupation of the Cavandish Laboratory at Cambridge under Sir J. J. Thomson, with the electron, and later under the leadership of Lord

[1] *The Organization of Industrial Scientific Research.*

Rutherford, with radio-active and nuclear studies; the study of low temperature phenomena at Leyden, under Kammerlingh Onnes; the development of the ultracentrifuge and its applications at Upsala by The Svedberg; the school of protein chemistry under Fischer; the schools of carbohydrate chemistry at St. Andrews under Sir James Irvine and at Birmingham under Professor W. N. Haworth.

Costly Apparatus of Research

With increased knowledge and consequent increased specialization in comparatively narrow fields and even more with the increase in the cost and complexity of special apparatus, convergent laboratories are bound to grow in number and importance. A great proportion of modern research work is dependent upon the invention and operation of new and extremely costly apparatus. The immense amount of work devoted to the design and building of ultracentrifuges by Svedberg naturally made Upsala a centre of ultracentrifugal studies and the cost of the installation contributed to this convergence of work. Even now there are in England only two Svedberg ultracentrifuges, one at the Lister Institute for Preventive Medicine and one at the University of Oxford, each housed in its own building with ancillary laboratories ministering to the needs of the machine and each operated by researchers who learned their technique at Upsala The electron microscope which carries the limits of useful magnification to some forty times that of the best optical microscope, is an expensive instrument needing experts to use it with profit and there are in England at the present time only seven of these instruments, all obtained from America under Lend-Lease.[1] Problems which need the use of such instruments naturally gravitate to the centres where they have been set up.

Another new and costly instrument, the cyclotron, was devised by E. O. Lawrence at the University of California and financed by a grant from the Rockefeller Foundation. The new giant model recently completed at the Carnegie Institution in Washington, will permit of the most precise measurements of the forces released by atomic disintegrations, but it is not an instrument of research that is likely to be installed in many institutions. It weighs more than 200 tons, cost about $500,000 and took four years to construct. A special three-storey building has had to be provided to house the necessary ancillary equipment and instrument shop and the cyclotron itself is housed in a chamber ten feet below ground level. It is obvious that the provision of such instruments spells convergence from the start, and the generosity of benefactors who make possible these powerful tools automatically creates convergent laboratories.

It is not necessarily the intention of endowments to do this, but in providing exceptional facilities they also dictate the style of the research

[1] A British instrument developed by Metropolitan-Vickers and delayed by the war will be available by the time this is published

that will be carried on. It is, to some extent, a matter of profitable investment. It is economically unsound to provide apparatus at fabulously high costs unless it can be used intensively. It is an unimportant matter if beakers, test tubes, balances and the other hundred and one small furnishings of normal laboratories are not in constant use but it is hardly to be expected that large sums will be expended either from private donations or public funds for apparatus that by duplication is used only occasionally in each centre. Again, the manipulators of the new and costly research tools must often be specially trained and can retain their skill only by constantly exercising it. They cannot return occasionally to the specialized implement and use it with speed, accuracy and assurance. For these reasons the machine dominates the nature of the work.

Convergence and Co-operation

Convergence, dependent upon the presence of costly apparatus is encouraged, albeit unintentionally, by scientists themselves. The scientist with a problem capable of advancement by the use of one of these tools finds it more expeditious and more satisfactory in results to present the problem to an expert than to attempt to learn the technique of the new instrument himself. After all, he does not wish particularly to become an expert in the new field He has his own interests which are often enough more than sufficient to keep him fully occupied. The expert with the research tool has, therefore, the opportunity of exploiting his technique in all kinds of fields and his experience grows apace so that he can obtain useful results either much more rapidly or, in some cases, where his less expert colleague would altogether fail. There is a natural gravitation of problems to the new tool, an increasing procession of Mahomets to the newly discovered mountain. In general, therefore, there is no need for large numbers of specialist and expensive apparatus. It is only necessary that the small numbers available shall be accessible to the scientific world at large Co-operation between laboratories and between individual scientists will do the rest

The convergence of work in laboratories where benefactions have provided peculiar facilities is largely fortuitous The only aim of the benefactors usually was to provide additional and much needed facilities and not to influence the character either of the work or of the institution Nevertheless, the money provided has done both. There are other benefactions that deliberately set out to provide convergent laboratories —to ensure that their outlook, interests, equipment, location and staffing, all tend to the fulfilment of one main purpose These are benefactions given, not alone for material provisions, but for research in special fields or directed to particular ends. The Rockefeller Institute for Medical Research in New York, the Lister Institute of Preventive Medicine in London, and Nuffield College at Oxford are examples of this kind of benefaction. With money provided for the pursuit of definite ends

great research institutions have been built up which have become outstanding in their selected fields. They are designed to draw to them all the problems of their central task and they become centres toward which men and problems converge. In a sense they are like the specialist apparatus except that the whole institution is itself the apparatus of research. The gravitation of men and problems gives them the vast experience denied to the divergent laboratory and creates from them centres of specialist learning that may be used by all. They are therefore called upon to co-operate in many related problems. Convergence and co-operation are becoming the key notes of modern large-scale research.

The twin features of convergence and co-operation in the organization of research are particularly noticeable in industrial research where a development of the last 25 years has been the emergence of the research team. The day of the divergent laboratory for industrial research has come and gone. The university laboratory, the general consultant and Fellowship laboratories and some kinds of Government laboratory, are now almost the only examples of divergent laboratories. It has already been pointed out that convergence began in the university schools of research but it is probably true that the divergent type remains the best for university teaching for, as is pointed out later, the main end is not necessarily the successful completion of the research, but the training of men.

Where the results of the researches are the chief object of the laboratory the trend to convergence is most marked One reason for this, the increasing complexity and expense of research apparatus, has already been considered. Another and more general reason is the increasing limitation of the field of knowledge exploited by one man. The growth of knowledge in the natural and technical sciences has so far exceeded the ability of individuals to do more than pursue it faintly that men have been forced to select for themselves limited horizons.

At the beginning of this century even, an outstanding man could be chemist and physicist and perhaps engineer and could undertake problems in a multitude of fields. To-day the same kind of man would not attempt to be more than an outstanding exponent of a small branch of knowledge, content to keep broadly abreast of the remainder of the related sciences. What is true of an individual is true too of research organizations, for the laboratories are in fact the reflections of the men who occupy them.

The Research Team

The principle of convergence in laboratories does not yet mean that one specialist problem only can be handled but rather, that all the problems subserve a common aim and march towards a common goal. With the increase in knowledge there may be many paths converging upon the goal and it is to meet this need that the conception of the

research team has emerged. The research team differs from the departmental organization in that while the latter has a hierarchy headed by a departmental head, the former is a team of specialists co-ordinated by a director or leader.

It is an absorbing study to see into what distant fields a single study may lead the experimenters. This is particularly true of applied or industrial research. The production of a new drug, for example, will quite normally involve the co-operation of biologists, chemists and medical men as the material is produced, tested, changed, retested and given clinical trials. If the trials are successful, production on a commercial scale may involve the co-operation of chemical engineers to design new plant, physical chemists to control and study bulk reactions, specialists in refrigeration or heat transfer or drying or high vacuum distillation. If the raw materials needed are scarce, the help of botanists, plant geneticists, and agricultural experts may be called in to increase the supply of a plant product: or coal tar or petroleum experts may be needed for an organic synthetic. The story could be repeated in almost any field.

Financing Research

Along with the increased complexity of research work there has developed, as might have been expected, an increased complexity in its organization, and the cost of modern convergent laboratories has extended the principle of co-operation, which is a corollary of convergence, to the method of their financing. The influence either inadvertent or deliberate—of the method of financing upon the work and style of a laboratory has already been mentioned There are now many different ways of financing research. At the extremes are laboratories financed at wholly private and wholly public expense Privately financed research is private property, the results are exclusive to the owner and need not be published. Publicly financed research, on the other hand, is carried on for the benefit of all and is public property. Between these two extremes are several intermediate courses.

The broadest classification on this scheme gives three groups of industrial, government and academic laboratories The first of these is privately financed and forms by far the largest group The second is publicly financed, while the third draws its financial resources from both and is a fair representative of the intermediate course. This simple classification gives no indication of the variety of modern research laboratories and a more complete classification which distinguishes the main well-defined types gives the following seven groups:

(1) University laboratories
(2) Endowed laboratories
(3) National laboratories
(4) Individual industrial laboratories

(5) Consulting laboratories
(6) Industrial fellowship laboratories
(7) Co-operative industrial laboratories

University laboratories, consulting laboratories and industrial fellowship laboratories are, in general, divergent in character, though the latter two may be restricted to specialist fields and are, as a rule, co-operative in practice. The other laboratories named are usually convergent in character, and with the exception of individual industrial enterprises are normally co-operative in practice. The force of the trend towards pooling will be apparent Co-operation in research has become the key-note in particular of modern industry.

All Research Co-operative in Spirit

In one sense all scientific research is co-operative for each research worker is dependent on his fellows and on those who have preceded him, blazing a short distance of the trail he is trying to follow. It is not only in the extensive use made of common services such as expensive and elaborate instruments but also in the even greater, if less spectacular, dependence upon libraries containing the carefully published and indexed results of innumerable researchers. No literature is so thoroughly combed, abstracted and indexed as that of science, and it is inconceivable that any major research problem should get under way without a preliminary search of the literature covering related work carried out in all the countries of the world. Every scientist is nourished on the ideas, even the mistaken ideas of his predecessors. In this sense, science knows no barriers of time or space. Successful research largely depends upon the co-operation of scientists, the free criticism of methods and results and the sharp play of mind on mind.

Perhaps the best example of international co-operation in science is afforded by astronomy in which, through the International Union for Solar Research, all the great observatories exchange results to an extent unparalleled in any other science. A most successful aspect of the work of the League of Nations, carried on through its health organization, was the organization of work in laboratories throughout the world to provide international standards for a whole range of modern biochemical remedies, starting with insulin and ranging through vitamins, hormones, antitoxins and chemotherapeutic products. It is no exaggeration to say that the successful application of many of these materials depended upon the work so encouraged and the standards so evolved. The new insecticide D D T was first discovered and recorded, though without reference to its insecticidal properties, by a young German chemist named Zeisler at Strasbourg in 1874 The Nobel prizes for scientific eminence are awarded impartially from the Swedish capital to outstanding men of all nations

International co-operation among scientists has been disturbed by

the war, but even its fevered rush has brought new opportunities for combined work. Penicillin, discovered, isolated and purified in Great Britain, has been developed to war production by American scientists and all its secrets have been communicated to the Russians. Even now there is a healthy rivalry, in which no advance in one quarter is secret from any other, to probe the secret of its structure and solve the problem of its synthesis Radio-location, another British invention, has been brought to its present production by American concentration of resources. There is a British scientific mission stationed permanently in Washington; the Americans have one in London. The Dominions maintain scientific liaison officers in both great capitals. The British Council's interests in China are looked after by a scientist whose task is to present the results of Western research to the Chinese scientists, and a representative of the Royal Society, which is itself a European rather than a British community, has carried on a liaison with the scientists of India.

It is not, however, with co-operation between scientists that we are concerned but with the more difficult achievement of co-operation among laymen, often with competitive interests, for scientific ends The gap between the co-operation of scientists in their work and the co-operation of laymen to receive the benefits, is bridged by the consultant and by the industrial fellowship laboratories In both instances facilities for co-operation are provided that are no responsibility of the participants in the research These are in fact, co-operative organizations run by scientists for the benefit of the sponsors of the research work In defining them in this manner it is not overlooked that the former is operated as a commercial venture for profit, nor that the latter, though non-profit-making in outlook, is dependent for this independence upon the generosity of benefactors not usually scientists It remains true that the co-operation of the sponsors of the work is not deliberate but is conditioned entirely by the circumstances provided for them This is evidenced by the fact that the results of the work are confidential to individual sponsors True co-operative research is dependent upon the deliberate intention of the sponsors to pool their financial assistance and to share, each to the best of his ability in the common benefits of the results. Three distinct classes of co-operative research of this kind may be distinguished, which may be designated community research, corporate research and co-operative research proper

Community Co-operative Research

In all civilized countries the state carries on, as one of its functions, certain types of scientific research The Physikalische-Technische Reichsanstalt in Germany, the Laboratoire Centrale d' Electricité in France, the National Physical Laboratory in Great Britain and the Bureau of Standards in the United States are typical of this kind of co-operation in research. Laboratories such as these are concerned

chiefly with the maintenance of standards of length, time, mass and quality; the determination of physical constants, and the definition of quality and performance; and the regulation through these standards of national commerce. It is apparent that such work can be carried on satisfactorily only in laboratories carrying with them the authority conferred by State ownership and control.

There are in addition large fields of investigation where the maximum benefit can be obtained only with government assistance. These are fields of fundamental importance to the whole community, such as the conservation of national resources, agriculture, public health, transport and housing which are all-pervasive problems in which the incentive to research is insufficient to attract private enterprise. In general, the number of units participating is very large and unco-ordinated, being in the limit each individual in the community, so that voluntary co-operation is difficult to attain Participation on a community basis through government intervention is the only way in these circumstances of providing the necessary centralized facilities. Laboratories thus established on a national scale are truly co-operative with all the citizens co-operating, albeit involuntarily, through the payment of taxes which provide the necessary funds. The characteristic of this kind of co-operation in research is its involuntariness Every citizen is willy-nilly a participator. Whether or not an individual wishes to see research carried out on particular problems is immaterial. It is the decision of the community, through its government, that the research shall be carried on and the individual has no choice but to subscribe. All such laboratories must answer the broad test of utility to the community. If, for example, the happiness, health and efficiency of the race depend upon the provision of good homes, then building research becomes an essential element of State policy in which all must unite for the benefit of all.

Corporate Co-operative Research

Corporate research, resembles community research in that it implies a similar centralized policy carried out by a single financing centre without necessarily consulting its individual members and using funds not necessarily specifically subscribed for the purpose of carrying on research. The central organization in such a case usually covers a limited field and represents a sectional interest for whose benefit it chiefly works although more general benefits to the community at large are not excluded There is also as a rule some degree of freedom of the individual in that there is no compulsion to subscribe to the organization Having agreed to support the central organization, the individual is, however, committed to the idea of a central research organization under a single directional control. Research by trade associations or professional societies are examples of the corporate style of co-operative research.

Voluntary Co-operative Research

Co-operative research proper, on the other hand, is the result of a voluntary association of individuals for the express purpose of conducting research for the benefit of all. The outstanding examples of this in Great Britain are the Research Associations sponsored by the Department of Scientific and Industrial Research and various independent groups such as the Therapeutic Research Corporation of Great Britain, Ltd. The participators in this true co-operative research are usually industrial concerns, interested in a common industry. The most frequent association is that of producers. The first world war inculcated the idea of co-operation for swift results and manufacturers having become accustomed to the principle of working together, recognized that the interchange of information previously regarded as secret, resulted in ultimate gain. Associations of consumers, although less common, are also known and exist usually to exert the pressure for modification and improvement which invariably arises from users who are in close touch with the requirements. Although this is the source of the demand for change, it is not usual for non-technical consumers to combine for research purposes and because of the diversity of uses of many products the incentive to common action breaks down. When the consumers are technically-minded, as in the case of manufacturers employing a product as a raw material, dual associations of producers and consumers may result. This type of association is common chiefly in the so-called *horizontal* industries such as the textile industry where the finished product of one section is the raw material of the next

Whether community, corporate or co-operative proper, association for the purpose of research has become an outstanding feature of industrial research, particularly in Britain. Of recent origin, its growth has been phenomenal and shows no signs of decelerating For this reason alone it is worth consideration but in addition the co-operative spirit in research bears within it seeds that, if properly cultivated, can assist materially in the solution of industrial problems peculiar to this country

III

CO-OPERATION IN RESEARCH

INDUSTRIAL INVESTIGATION HAS progressed steadily under the incentive of necessity from the occasional inventiveness of individuals, through the training of scientists and the provision of collective facilities for them in specialized laboratories, to the co-operation of would-be bene-

ficiaries in centralized establishments What are the essential characteristics of such co-operative organizations and how do they differ, if at all, from independent, privately owned and privately financed laboratories? What are their advantages over the independent industrial laboratories and what are their disadvantages? Upon the answers to such questions will depend the extent to which a case for co-operation in research can be established. We are not setting out here to demonstrate the value to industry of scientific research; concerning this there is no longer any doubt in the minds of responsible individuals. Rather is it the aim to examine a much more restricted field, namely the need for co-operative research in industry—and in particular British industry.

Individual and Co-operative Research

One point must be established at the outset; co-operative research organizations are not competitors with other types of research laboratories. They supplement rather than replace individual laboratories. It should, in fact, be the proudest boast of any centralized research establishment, that not only has it contributed original knowledge to the industry it serves, but that by its stimulus it has encouraged the formation of new laboratories and the expansion of already established ones. The research association that fails to encourage and inspire research activity on the part of its members is failing in a part of its function. It should not be possible for it to be regarded by its members as a substitute for individual research. The greatest return from the work of the central laboratory will be garnered by those firms and individuals whose technical abilities enable them to seize avidly upon the work of the association laboratory and turn it to account. This feature of the co-operative system was recognized from the first by the Advisory Committee of the Privy Council for Scientific and Industrial Research, which reported in 1916 in the following terms:

> "Co-operative research, when it has done its utmost, will always leave ample room for individual initiative and ability in the application of its results, more than sufficient as an incentive and as a means to outstanding success. Co-operation is not the negation of individual effort, it raises initiative to a higher power."[1]

While, therefore, the results obtained by the association may be of great importance to industry, it is conceivable that they will be secondary to the indirect benefits conferred by the stimulus of independent research.

There is a repercussion of this on the research association itself in that the more independent research is stimulated and the greater the numbers of appreciative minds thereby produced, the more free is the central organization to devote itself to fundamental tasks. It must not be forgotten that the task of the co-operative laboratory is to work

[1]Report of the Committee, 1915–16 (Cd 8336) p. 14.

for an industry and not for selected individuals and this can best be accomplished by fundamental studies The application of the studies can safely be left in the hands of competent individual industrial laboratories, speaking the same language as the central laboratory, appreciative of the implications of its fundamental discoveries and applying them independently to specific problems with satisfactory results. Without this essential background in the industry, the co-operative laboratory must devote time and resources to applications of fundamental work which diminish the energies remaining and may at best serve only sectional interests. The central laboratory should be the nerve centre of technical progress in industry, but to be this it must have executive muscles to activate in the laboratories of individual firms

The importance of the individual firms' laboratories cannot be over-emphasized. There are some branches of research work which, though they must be done, do not fall naturally to a central laboratory to perform The co-operative laboratory works for the industry. It cannot therefore occupy itself with the development of competitive products. Standard products common to the industry, the study of generally-used raw materials, the improvement of standard processes and methods, the introduction of testing procedures are all suitable topics for co-operative research. Always the search must be for broad topics of general benefit and this normally means, sooner or later, the investigation of fundamental problems. It is here that the research association comes fully into its own

Fundamental research is the nourishment of industrial growth Applied science lives upon it but it cannot continue indefinitely to draw sustenance from the fundamental research of the past Fundamental and applied research are twins, and must grow together, each reflecting the characteristics of the other—suffering together, flourishing together, linked inseparably in the ups and downs of their existence C E K. Mees has stated that three kinds of laboratories are essential to industry —routine laboratories for works control, applied laboratories for the improvement of products and processes, and research laboratories for fundamental investigation. It is from the third kind that all marked effects of research have come.

The momentum of industry is such that the demand for fundamental research to meet its evergrowing needs increases daily. But fundamental research needs patience, time and money to bring it to a successful issue and to meet the need the co-operative laboratory is ideally suited Of the industry but not immersed in the daily struggle, it can appreciate the problems and concentrate upon their solution in an atmosphere of detachment. Yet its ultimate connection can, when necessary, imbue it with the sense of urgency sustained by the industrial tempo For much of its fundamental work in the past, industry has been dependent on the university laboratories which have a traditional lien on this branch of research, but the needs of industry have outgrown the

productive capacity of the universities. When needed in a hurry as it so often is now, the industrially connected laboratory is its natural home. Fundamental research was commenced at the great American firm of E.I. du Pont de Nemours in 1927 because "it was felt at that time that university research while very valuable, was not sufficient to fill the existing gaps in scientific knowledge of importance to the fields of activity of the company."[1]

Research in the Universities

It is in industry and in the laboratories connected with it that the major part of fundamental research must be done in the future. This is not to say that universities and colleges should not carry out research but they can hardly expect to compete with the industrial laboratories. Not only is expensive equipment provided on a more lavish scale but, of greater importance, the available labour is of a more experienced and higher quality Industrial laboratories, whether individual or co-operative, are not dependent upon immature students nor upon a changing population. In an industrial laboratory of high calibre, not only is the director an outstanding personality but the individual workers also are men of experience, originally chosen for their research abilities and by the permanence of their appointments continuity in the prosecution of a programme is provided for. Nevertheless, the characteristic of universities which gave them their original pre-eminence in this field, namely detachment, is still a desirable one for the conduct of long term fundamental research and it is this combination of the virtues of both individual industrial laboratories and detached university schools that gives the co-operative laboratories of the research association type their unique opportunity.

F. C. Toy has pointed out[2] the value for fundamental research of the intermediate position of research associations, with their contacts with the universities on the one hand and their comprehensive mental picture of their industries on the other Any failure to do fundamental work must, in his view, be due to lack of resources rather than to any characteristic of their position in the country's organization for research.

The universities have one advantage which cannot be matched in any other kind of laboratory However academic in style the research work in industry may appear, it is in the last analysis conditioned by the needs of industry. Industrial research now implies, more than ever before, a deliberate systematic effort rather than promiscuous and tentative enquiries. But in the universities complete freedom still reigns The direction of research is dictated not by any express need but solely by the interests and curiosities of the researcher's mind This freedom enables unexpected and unpredictable tracts of research to be uncovered The marking out of a new field without apparent or immediate value

[1] L K Bolton Chemical Director, E I du Pont de Nemours speaking on receipt of the Perkin medal, Jan 5th, 1945

[2] *Nature* 1942, Vol 150, p 373

is pre-eminently the kind of research for which the universities are fitted. Industry, however, cannot be expected to wait upon the vagaries of personal inclinations for investigations in fields which necessity lays bare.

Academic institutions have, too, of course, a further function of vaster importance to industry and the community than the production of research results. The primary functions of the universities are to preserve and transmit knowledge. They must be storehouses of scientific knowledge which can be made available to all. It is no longer so much their task to expand knowledge as to conserve it and to hand it on, digested and systematized, to succeeding generations of students. It is to the universities that industry must look for the supply of trained scientists and it is by the numbers and competence of the men they turn out that the success of the universities must be judged. Their primary function is to train men and not to do research.

The research function, from which universities must not be barred, arises out of the educational, and the research fields should be chosen not so much for the results they may yield as for the training they afford to promising young men and the stimulating atmosphere they create for the teacher. No less an authority than Lord Rutherford, speaking at a Conference of International scientists in 1938, pointed out that "It is imperative that the universities should be in a position not only to give a sound theoretical and practical instruction in the various branches of science, but, what is more difficult, to select from the main body of scientific students those who are to be trained in the methods of research. Experience has shown that the progress of science depends in no small degree on the emergence of men of outstanding originality of mind who are endowed with a natural capacity for scientific investigation and for stimulating and directing the work of others along fruitful lines."[1] In the light of this requirement, specialization in academic research must be regarded with considerable apprehension.

Functions of the Co-operative Laboratory

Co-operative laboratories, through their position in the research hierarchy, are able to discharge certain functions and exercise influences that could hardly fall to the lot of any other organization. By working for a whole industry or a group of related industries they obtain a comprehensive view that is denied to others. Narrow, sectionalized interests, have no place in the co-operative scheme; a laboratory that indulged in them could not for long be successful. It is of the utmost value to industry to have what amounts to a local encyclopædia of technical and scientific information to supplement their own specialized information. By working for a collection of industrial concerns in the same industry, the centralized laboratory is able to bring out the essential common interests that they share and by so doing, is able to make a notable contribution to the elimination of secrecy.

[1]The *Times*, January 4th, 1938.

The comprehensive view and the emphasis on the common interest enable co-operative research organizations to provide a trainee scheme for industry which, by producing a core of scientifically trained men, materially assists the industry in the absorption and application of new ideas. This aspect is of particular value in the older industries which, existing successfully before industrial research was thought of, may find it difficult to recognize the implications of the challenge of the new competition. In the so-called horizontal industries, the central research laboratories also provide the evidence of the essential technical links between the strata of the commercial organization Research to many firms is a form of insurance and the co-operative organization meets this aspect ideally, inasmuch as it exhibits the main characteristics of all insurance, namely, the spreading of costs and the sharing of returns.

Economics of Co-operative Research—Finance

The separate advantages detailed in the last paragraph may appear individually small but together they form a strong incentive for co-operation. The spreading of costs referred to brings us, however, to consideration of a most important feature of this particular method of conducting research—namely economy. According to Mr. Samuel Courtauld[1] the cost of research practised on the most liberal scale known anywhere is only a fraction of the value it demonstrably creates. Unfortunately, it is also true that research, practised on the modern scale, is a most costly undertaking. In diversified fields, in particular, large institutions are required to cover adequately the ramifications of any problem. It may be economical to operate these large institutions but it is far from economical to duplicate them.

It must not be thought that mere size is sufficient to ensure economy. It is not necessary in research to be large to be efficient, but it is true that where problems touch more than one science and where they must be attacked from several different angles, experience has shown that the co-ordinated team is the most effective and economical method of handling them. Industrial research on this grand scale may therefore seem to be the perquisite of the great corporations. It is reported that the production of nylon would have been impossible without the expenditure of millions of dollars on research and development. The growing importance of the research team favours, therefore, the large corporations.

For medium sized laboratories it is a usual estimate that the annual cost is approximately equal to the capital cost. As the laboratories become larger and as more and more specialized and expensive equipment is purchased, the annual cost decreases in relation to the capital expenditure. A laboratory costing, say, £10,000 to build and equip may reasonably be expected to cost about the same sum annually to maintain, while a laboratory costing, say, £250,000 may not cost more than about one half that sum annually to maintain.

[1]The *Times*, November 1st, 1943.

Looked at in another way the cost of research may be estimated as the cost per research man. The Industrial Research Institute of New York recently issued a questionnaire, from the answers to which it was estimated that an average figure for research was $10,000 per research man per year. The National Resources Planning Board, which made a similar survey in 1940, estimated $4,000 per man per year for all staff including assistant and clerical staff These two estimates are not, therefore, incompatible and the figures may be accepted as reasonable for American industry. Similar figures for Great Britain have not been obtained, but it is probable that they would be of the same order or a little less. In any individual instance it might be rather higher or lower, but it is reasonable to suppose that the average inclusive cost of research work in Great Britain would not be far short of £800 per man-year.

The large corporations have a great advantage in being able to afford to carry on the pioneering work necessary to make outstanding advances. They can, and do, spend lavishly on large and diversified research laboratories and they reap the abundant reward of such expenditure. But small units have the same need for research as big units The fundamental problems of large and small firms in the same industry are identical; they differ only in degree. Problems relating to the supply of raw materials, the economy of processing, the improvement of products and the fitting of the products to the needs of the consumers, confront them all and because of this similarity of needs there is much to be said for investigating long range problems on a full industry basis rather than on the basis of individual firms. In industries comprising many small units, provided they have a common interest in advancing their technical and scientific knowledge, the development of one or more central co-operative organizations is the chief hope that the small firm has of obtaining the advantages of research otherwise available only to large corporations.

A small firm with a limited capital may perhaps, if exceptionally progressive, decide to devote some part of its resources to research. Suppose it decides to employ one or two scientists. The cost will depend, of course, upon the calibre of the scientists, but even on this modest scale it can hardly be less than £500 to £1,000 a year plus the laboratory expenses—accommodation, fittings, heat, light, water, chemicals, etc. Under such circumstances it is probable that the accommodation will be cramped and the facilities limited. The limited capital available may force the employer to demand quick returns. Unfortunately, there can be no guarantee that the £1,000 so spent annually will produce results of value in any measurable time. The edge of the first fine fervour may well be blunted if results are long delayed and hardly-spared money is flowing steadily down the laboratory drains.

What has this to do with co-operative research? Simply that this method of financing research makes it possible for small firms in particular,

though large firms are not excluded, to participate for exceedingly modest sums in researches costing far beyond anything that they could otherwise contemplate. Instead of an extremely precarious £1,000 or so, a subscription to a central laboratory of, say, £50, which is a normally average annual subscription to a research association, assures participation in research expenditure amounting to anything from £20,000 to £100,000 a year. This miracle of investment return is the logical outcome of a logical attack upon an otherwise intractable problem.

The especial advantage of the co-operative research idea to Great Britain will be apparent Large corporations do not constitute the major part of British industry. More than any other country, perhaps, our individualism has shown itself in the preponderance of small, often privately financed, firms According to the 1930 Census of Production of the Textile Trades, more than one half of the production comes from firms employing less than 300 operatives. The 1935 Census of Production shows that out of a total of 173,502 firms included in the census, no less than 163,552 or 94 per cent. employed less than 100 persons each while, according to the Annual Report of the Chief Inspector of Factories and Workshops for 1937, only 18 per cent. of all the workers employed in factories were in concerns employing 1,000 or more, and 52 per cent. were employed in firms with a pay-roll of 250 or less. Sir Harold Hartley has put the same problem in another way[1] by pointing out that in our five largest industries there are nearly 5,000 undertakings of which only 126 employ more than 1,000 persons. For industry organized in this way, special arrangements are needed to cover the demand for expensive projects such as research. The co-operative research organization is the answer to the need.

Economics of Co-operative Research—Personnel

If financial economy is a potent argument when considering the needs of industry, the economy in personnel is doubly so when the problem is raised to the national scale. Every major country is conducting industrial research on an increasing scale and in most cases with possibilities of continued expansion that must inevitably be denied to Great Britain. We have behind us an excellent tradition of research. The names of Dalton, Faraday, Kelvin, Perkin, Harvey, Lister and many others stud our scientific firmament. But in modern research, conceived on the grand scale, a few great names are not enough. Whole battalions of ardent, competent, enthusiastic and experienced researchers are needed. Nations like the United States with a population of 130 millions, Russia with 170 millions, and China with 450 millions, have entered this race and bid fair to provide a competition impossible to meet.

It is not quality that we have to fear; on this score we need have no doubts. British scientists are every whit as capable as those of

[1] *Are you Research Minded*, 1943.

any other country. Our industrial history, after making allowance for the providential proximity of necessary raw materials, testifies to the ability of our numerically restricted scientific population. The second world war has demonstrated that we have not yet lost the ability to lead the scientific world. Radio-location, penicillin, anti-lewisite, and jet propulsion, to name only a few that have obtained some publicity, are all British developments. But for how long this position can be maintained is open to conjecture. The importance of mere numbers must not be overestimated but it cannot be neglected.

Statistics regarding research expenditure in different countries are difficult to obtain and more difficult to interpret, since the meaning attached to the term research is so wide. It is not surprising, therefore, that recent estimates do not agree in detail but they do all point significantly to the circumstance that Great Britain is falling behind its great industrial competitors in research expenditure. A report of the Parliamentary and Scientific Committee[1] estimated the expenditure on research of the United States to be ten times that of the United Kingdom. Viscount Samuel drew attention in the House of Lords[2] to the National Research Council's figure of 2,200 laboratories in American industry employing 70,000 scientists at an annual cost of £60 millions. British industry on the other hand, according to the report of the Federation of British Industries' Industrial Research Committee[3] was employing in 1928 some 5,000 scientists at an annual cost of £5½ millions. This same report pointed out the imposing record of British research achievement and that the majority of industries upon which modern civilization rests were originated in this country. H. M. Tory, in an address to the Canadian Club in Ottawa in 1943, estimated Russian Annual expenditure on research at between £75 millions and £125 millions in 1934 Bernal[4] set the United States expenditure at £75 millions in 1935, and the Association of Scientific Workers,[5] gave the British expenditure as £7½ millions in 1934.

The disparity between the estimates for Great Britain and those for Russia and the United States is terribly apparent But, if reduced to the basis of cost per head, it seems that this country is not even doing as much as it could. Sir Harold Hartley[6] quoted Russian expenditure on scientific research at 1·0 per cent of the national income, American at 0·3 per cent. and British at 0 1 per cent

The mere expenditure of money is admittedly a poor guide to the output of research. Much outstanding work has been accomplished with little financial resources by exceptional individuals, but by and

[1] *Scientific Research and the Universities in Post-War Britain*, October, 1943.
[2] July 15th, 1943
[3] *Industry and Research*, October, 1943
[4] *The Social Function of Science*, 1939
[5] *Proceedings*, January, 1943
[6] *Are you Research Minded*, 1943.

large it must be true that the greater the expenditure the greater the number of persons employed and the correspondingly greater likelihood of a substantial return on the investment. Unfortunately, while it is true that Great Britain could spend more on research than it does, it would remain impracticable to compete with our larger industrial rivals. The scale of the country is different and it is impossible to find from our limited population sufficient scientists of ability to spend the money to advantage. What we lack in numbers, therefore, must be made up in organization. Compared with the armies of researchers already available in Russian and American laboratories and the potential of newly awakened countries like China and India, the number of researchers in Britain is lamentably small, and it is essential therefore that, in industrial research, their work should be co-ordinated and planned to produce the greatest possible return. The organization to counteract the population disparity is to hand. Tested already on a limited scale, the method of co-operative research whereby the many share in, and benefit from, the work of a comparative few gives us the instrument we need. Co-operative financing and the pooling of results spread the cost and multiply the benefits abnormally. The limit imposed is neither the money available nor the number of men that can usefully be employed, but the individual's ability to take advantage of the accumulated knowledge.

It may perhaps be argued that an organization that can so usefully multiply the effects of research in Great Britain is equally applicable to our competitors. In theory this is, of course, true, but in practice it seems that the co-operative procedure is not a natural inclination and is born only of necessity. So long as the numbers of scientists available remain sufficiently large in relation to the demand, it is unlikely that co-operative research will be practised. Evidence for this may be found in the United States where, despite considerable experimenting in the organization of research, the co-operative system has until now played a negligible part. The increasing tempo of research output is beginning to strain the resources even of that great reservoir and, in consequence, the establishment of co-operative laboratories, usually operating on the fellowship or foundation principle as distinct from the association principle practised in Great Britain, is being considerably accelerated

Problems of Co-operative Research

It must not be thought that the co-operative idea in research is without its problems nor that its benefits are obtained without price, but experience is indicating increasingly how to solve the problems and industry is realizing increasingly that the price exacted is a small one. At the initiation of what has become the British system of co-operative research through research associations assisted by the Government, it was widely held that the field open to this kind of development must

necessarily be limited. The problem of how to secure the pooling of information and ideas in competitive industry was much to the fore. Time has shown that the industrialist, once the need is recognized, has not been backward in sacrificing the privilege of secrecy. It is, indeed, the recognition by an industry of the need for research that constitutes the major step in the formation of successful central research organizations. The generalized worship of research as an abstract but desirable adjunct of business, which seems periodically to infect communities, is not a satisfactory foundation upon which to build. A genuine recognition of personal necessity provides a surer basis and with it, the chief obstacles in the industrialist's initial approach, are usually overcome.

Not so easily settled are the problems of the research association itself. It still has to justify its existence and co-operative research is young in experience of handling its problems The first problem, and it is a recurring one, that confronts the research association is the selection of problems on which to work It has to work for the industry and not for individuals The problems must not be of too general a character or they may fail to win any interest but, on the other hand, they must not be of too immediate a practical application or they will almost certainly tend to sectional benefits

It must be clear to the industrialist from the outset that he cannot expect quick profits from his investment, but equally it must be recognized by the laboratory that industry cannot be satisfied indefinitely with abstruse scientific papers in the more exclusive journals. A nice path must be trodden, therefore, by the research association between the Scylla of superficiality induced by the desire for immediately applicable results, and the Charybdis of aloofness dictated by the necessity for fundamental investigation This problem has not yet been satisfactorily settled by all co-operative research organizations

One by-product of experience stands out, namely, the necessity of defining the objectives to be aimed at This might have been anticipated, for it is a necessary condition of all research But in co-operative research, where the temptations to vague and ill-defined ends are most pronounced, it is imperative that definitions be clear and unequivocal This is perhaps the most difficult task of the research association, but only by conquering it can the maximum benefits of the co-operative scheme be achieved

A further problem confronting the centralized laboratory is the lack of the competitive stimulus However much we may extol the scientific attitude, the stimulus provided by the existence of similar laboratories cannot be overlooked Competition, which is reputedly the life blood of business, is a useful corrective for a research organization In the individual industrial laboratory this is provided by the immediate industrial connection and the knowledge of other laboratories in competing firms, each striving to keep ahead partly for commercial reasons

but also for reasons of prestige The single co-operative laboratory lacks this stimulus and there is a real danger that co-operation may also spell mediocrity. The way of escape from this entanglement is also not yet clear to all centralized laboratories but it is evident that duplication of laboratories may not necessarily be wasteful In chronic cases it may provide the needed fillip. Britain's scientific population demands co-operation for its maximum utilization, but a balanced view of the need for duplication of work may be necessary to ensure that maximum utilization also provides maximum returns.

It is considered by some that the danger of mediocrity in personnel and output is increased under the British system of State aid. It seems certain that, while some fields are essentially the province of government research establishments, it is not possible to run a research laboratory on the lines of the Civil Service. The justifiably proud record of integrity enjoyed by the Civil Service is not sufficient for research. To be right in all the circumstances appertaining at the time is the demand of government service, but to be enterprising and to take risks, to bend the circumstances to man's will and benefit, is the prerogative of research. In research it is not necessary to be conformingly right all the time; to be brilliantly unconventional may produce more fundamental and enduring results.

The danger of mediocrity is the constant companion of many research associations through lack of financial resources. In industries comprising large individual corporations there is a likelihood that these will spend money allocated to research upon their own establishments. Small firms, on the other hand, may not recognize the value to be obtained from the co-operative association or, through technical weakness, may be unable to take full advantage of it The half-hearted support which results, may mean that the research association is always financially embarrassed. In a despairing attempt to cover the field, the temptation to employ large staffs of ill-paid and mediocre men is very great and only great courage and unwavering faith in the value of a high standard can resist it Research runs on brain-power and large numbers are no substitute for poor quality. As in other fields of human endeavour, a good big one is to be preferred to a good little one but it cannot be over emphasized that it must be good.

Mediocrity has been stressed here because it is often considered to be the besetting sin of co-operation, not alone in research but in any field, and it may be encouraged in so many different ways. There is, too, a difficulty of initiation that often manifests itself. To achieve its best results the co-operative association should comprise all the firms in the industry it serves. This ideal is seldom reached, but for success it must be substantially attained. This is particularly so when government assistance is afforded to the organization since, otherwise, public funds may be devoted to sectional interests that do not stand to benefit the community which ultimately provides the funds.

In spite of the dangers and possible disadvantages co-operative research in its infancy has proved its value. The dangers can be avoided as has been demonstrated by the success of such organizations as the British Cotton Industry Research Association and the Electrical Research Associations in this country, and the Mellon Institute in the United States of America. It still remains to generalize their formulæ for successful co-operative industrial research so that all industry may benefit from their experience. If it is conceded that industrial research is necessary in the modern world, it must be accepted that in Great Britain co-operation for this purpose is inevitable.

The need for research requires no arguing. On every page of financial reports, in serious journals such as the *Economist*, in parliamentary speeches, the need for the future technical efficiency of industry is emphasized. The relative decline of Great Britain in technical efficiency between the wars can be traced to the dangerously low ebb to which scientific research in this country had on the whole receded. The occasional brilliant individual was still there but he was no longer sufficient and, as a country, we lacked the means to develop to the point of use even such discoveries as were made by these solitary stars. The Minister of Production has pointed out[1] the unlimited power that modern science, engineering and business have given us to make good our wealth and stated that two or three fundamental inventions may well replace the capital wealth spent in the war. But two or three fundamental inventions do not come from the employment of two or three scientists and when they do come, they need the driving force of co-ordinated attack to drive them to the point of commercial application. The full force of the unlimited power inherent in industrial research can be realized in this country only if the maximum use is made of its scientific resources. The essential role of co-operative research in the nation's economy is clearly defined.

IV

CO-OPERATIVE RESEARCH IN GREAT BRITAIN

CO-OPERATIVE INDUSTRIAL RESEARCH is in some respects more advanced in Great Britain than elsewhere, partly because of the peculiarly suitable conditions for its development to be found in our ancient industries, the relative smallness of the majority of our industrial enterprises and

[1]Speech at Oxford, November 26th, 1943

the fewness of our scientific population, but also because of the strong lead and the incentives afforded by Government assistance over a long period. At the same time, the effect of Government assistance has been to produce a restricted pattern of organizations compared with the varied experimental approach to the same problem in, for example, the United States. This is not to say that research in Great Britain is regimented into uniformity. With the British genius for making systems work without undue organization, the research system of the country is a loose and many-sided adaptation of organizations originating in different ways from private benefactions, collective action and State intervention. It is difficult, therefore, to present a connected or systematic account of co-operative research conducted in Great Britain.

Research by Government Departments

As in other countries the various Government Departments conduct a considerable amount of research on a national scale, although many of them rely wholly or partly for scientific work and advice on the Department of Scientific and Industrial Research. The Service Departments carry out extensive specialized investigations into military, naval and air problems and the latter, as is to be expected, has contributed largely also to the advance of civil aviation. During the war the Supply Departments—Ministry of Supply, Ministry of Production, Ministry of Aircraft Production and also the Ministry of Home Security have conducted much research relating to problems peculiar to their responsibilities, while the Ministry of Food has a Cereal Research Station at St. Albans. Among the peace time Government Departments, the General Post Office maintains a large research and development organization with headquarters at the Dollis Hill laboratories.

Perhaps the greatest volume of research work undertaken in this way is devoted to agriculture and fisheries and is the responsibility of the Ministry of Agriculture and Fisheries, the Department of Agriculture for Scotland and the Development Fund. In addition to research stations for which these Departments accept various degrees of responsibility, the former has its own veterinary and plant pathology laboratories and has recently set up an Agricultural Machinery Development Board. Agricultural research is also the prime responsibility of the Agricultural Research Council established in 1931 and responsible to the Lord President of the Council [1] To ensure the rapid application of research results to practical farming, Agricultural Improvement Councils have been set up to advise on the testing of promising lines of research, to advise on farming problems that appear to need research, and to expedite the acceptance by farmers of useful new knowledge. The Development Fund was established by Parliament in 1909 under the Development and Road Improvement Funds Act. The Fund was to be used, among other purposes, for 'aiding and developing agriculture'

[1] *See* page 59.

and for 'the development and improvement of fisheries'. Fisheries investigations are divided into two classes, namely, definite economic problems which are the responsibilities of the Fisheries Department and marine biological problems which are carried on by independent institutions, receiving the bulk of their resources from the Development Fund. The Departments maintain laboratories at Lowestoft, Aberdeen and Conway, while independent laboratories are situated at Plymouth, Newcastle-on-Tyne, Port Erin, Millport and Windermere.

The Ministry of Fuel and Power includes in its responsibilities the operation, through the Safety in Mines Research Board, of a station for the investigation of problems relating to safety in coal mines, and also the scientific work connected with Gas Testing. The Ministry of Works and Buildings carries on development work by means of full scale field trials of promising research work. The Government Chemist's Department is the responsibility of the Treasury and operates the Government Laboratory, established in 1842, for scientific work connected with the collection of revenue. Its function has since been widened to enable it to undertake chemical work for any Government Department.[1]

Beginnings of Co-operative Research

Dominating the whole structure is the Department of Scientific and Industrial Research which operates in the field of industrial research largely by two methods, the conduct of investigations in its own research stations, and the assistance of Research Associations planned by co-operative industrial enterprise in conjunction with the Department The Department of Scientific and Industrial Research came into existence during the last war, but co-operative research and closely related projects had been essayed previously on various occasions going back into the last century.

The first Government venture in this field occurred in 1851 with the Great Exhibition, credited to the energy and initiative of the Prince Consort. The National Physical Laboratory was established in the year 1900 with the assistance of a grant of £13,000 from the Government, and was placed under the control of the Royal Society The laboratory was opened in 1902 by the Prince of Wales who commented on the fact that this undertaking was "almost the first instance of the State taking part in scientific research". Co-operative scientific research in Great Britain has, from the first, been pre-eminently a concern of the Government. Reference has already been made to the establishment of the Development Fund in 1909

As had been found earlier, the demand for scientists could not be met by the existing facilities and, here again, Government intervention came to the aid of industry by the foundation in 1907 of the Imperial College of Science and Technology The significance of this institution

[1]The scientific work of the Department of Overseas Trade and the Colonial Office are described in Chapter V

is that, unlike the newly formed Universities and technical colleges, the Imperial College was largely a community co-operative venture. The Government transferred to it the Royal College of Science and the Royal School of Mines and made an annual grant of £20,000 a year for its upkeep, while the Commissioners of the 1851 Exhibition made a grant of land at South Kensington. It was the object of the Institute to give the highest specialized instruction and the most advanced training in research in science, especially in its application to industry.

Not all the co-operative research in the early years of the century was carried out, however, with government aid. In 1901 the Institution of Civil Engineers set up an Engineering Standards Committee which was later enlarged to include all the main engineering institutions. This Committee, although it did not originally carry out research did, through technical Sub-Committees, produce a considerable degree of co-operation between engineering firms and paved the way for later research The first attempt at genuine co-operative industrial research in this country was probably that of the gas industry which, in 1907, established through the Institution of Gas Engineers a research fellowship at the University of Leeds. A Joint Committee of the Institution and the University —the Heating by Gas Committee—was formed and the association thus initiated has continued uninterruptedly. In 1910 the Livesey Professorship of Coal Gas and Fuel Industries was founded.

Other co-operative efforts of the corporate type had also come into being before the advent of the first world war. The Institute of Chemistry, for example, was conducting research on laboratory glassware and optical glasses at King's College, London, and the Institute of Metals was responsible for a research on the corrosion of non-ferrous metals at the University of Liverpool.

Influence of the First World War

These spasmodic efforts, when taken together, were extremely modest in view of the tremendous problems facing industry and it is not surprising that the outbreak of the first world war found this country completely unprepared industrially to meet the challenge. For the first time in history a war was to be fought on a national footing with industrial production equally as important as the fighting Services, and industrial production looked like losing its battle. It was only under the impact of war that the world's workshop realized the extent to which it was dependent upon other, now enemy, countries for its essential requirements The loss of its pre-eminent position had been so insidious that the need for strenuous technical efforts to recover lost ground went unrecognized until catastrophe manifested it Optical glass, for military and naval instruments, drugs for civil and military purposes, magnetos for aircraft and land transport, tungsten for steel alloys and zinc were among the items that British manufacturers found barred to them.

Government, industry and science were all stirred to action by the

revelation of the straits into which the country had fallen. Early in 1915, the Royal Society and other learned societies specially interested in chemistry, sent a deputation to the Presidents of the Boards of Trade and Education to urge "Government assistance for scientific research for industrial purposes" only to find that the Government, already aware of the situation, had laid plans for the assistance of all science affecting industrial development and by July of that year a White Paper[1] was issued in which was outlined a "Scheme for the Organization and Development of Scientific and Industrial Research" An Order in Council in the same month set up the Committee of the Privy Council for Scientific and Industrial Research with an Advisory Council. The pattern for co-operative research in Great Britain for an indefinite period ahead was being established and indeed this was definitely envisaged in the White Paper which quoted as one of the objects of the new proposals the establishment of "a permanent organization for the promotion of scientific and industrial research". The system that was to dominate the future co-operative research of the country was born under the stress of war. It is doubtful if it would have been born in any other circumstances.

At the same time parallel stirrings of interest were observable in industry. The engineering industries, the pottery industry, the silk industry were all being badly hit by the loss of materials or the loss of trade and were taking steps through their trade associations to rectify the position by the application of science The growth of trade associations for commercial reasons was a major element in deciding the direction which co-operative research in Great Britain was to take, for it was through those associations already in existence that the British manufacturer, temperamentally averse to collaborative effort, first learned its value, and in them found voices that could speak collectively for industry.

The Silk Association, formed for the purpose of settling prices, enlarged its scope to include the prosecution of research for the industry The British Engineers' Association, the British Electrical and Allied Manufacturers' Association and the Staffordshire Potteries Manufacturers' Association seeing their industries in danger decided similarly The Rubber Growers' Association raised £5,000 a year for research into the problems of rubber growing and latex preparation, while the Federation of Master Printers had at this time reached the position of directing attention to the need for research into materials of enemy origin used in the printing industry The Paper Makers' Association had looked abroad and in a report to the Board of Trade pointed out the desirability of a central research institute resembling the Charlottenburg Institute in Berlin.

It was the Engineering industries, however, through a Committee set up to consider education and research, that first gave conscious

[1]Cmd 8003

expression to the direction of events by declaring it a function of their organization "to develop co-operation between engineering firms" particularly because of "the comparatively small establishments (and smaller research departments) of most British engineering concerns". On all sides the tide was flowing strongly in a single direction, the establishment, under the joint auspices of government, industry and science, of trade associations specifically devoted to scientific research. This was the master plan of British co-operative industrial research which has persisted and predominated in this sphere of British industrial enterprise.

The Department of Scientific and Industrial Research

The execution of the plan began in the following year In December 1916, the Lord President of the Council announced that the Committee of the Privy Council for Scientific and Industrial Research had been converted to a separate Department responsible to Parliament through its own Minister and with its own financial vote. At the same time the Imperial Trust for Scientific and Industrial Research was created and held a sum of £1 million voted by Parliament for the work of the Department. The chief purpose of the 'Million Fund', as it became known, was to provide by financial assistance the necessary impetus to the formation of associations to carry on research for industry on a co-operative basis

The Department of Scientific and Industrial Research as instituted had three main functions: to institute specific researches for necessary purposes, to establish or assist in establishing research institutions for particular industries, and to encourage the training of scientific students in research methods to ensure an adequate supply of trained researchers. After a survey of the field of operations the Department settled down to its task which, in scope, has embraced all the natural sciences and all industries with the exception of medicine which is catered for by the Medical Research Council established in 1920, agriculture, which is catered for by the Agricultural Research Council established in 1931, fisheries and forestry.

Its first move was the support of *ad hoc* researches deemed to be necessary in the national interest and for the most part carried out in university and technical college laboratories. The support of individual researches of promise has continued to be a function of the Department. The early surveys revealed the existence of fields which could best be covered by community co-operative research, *i.e.*, by research under the direct control of the Department. As early as 1916 the Fuel Research Board was set up and plans were immediately set on foot to establish a research station, and in the following year, the Food Investigation Board was established. Responsibility for the National Physical Laboratory was transferred from the Royal Society to the Department in 1918 and in 1919 the Geological Survey and Museum were transferred from the Board of Education to the Department.

In 1944 the Department was operating twelve research stations and laboratories for the conduct of the greater part of its own work,[1] namely:

The Fuel Research Station at East Greenwich with eight local laboratories for the Coal Survey in different parts of the country.

The Food Investigation Stations at—Cambridge (Low Temperature Research)
Aberdeen (Torry Research Station)
and East Malling (Ditton Laboratory).

The National Physical Laboratory, Teddington.

The Chemical Research Laboratory, Teddington.

The Geological Survey of Great Britain, London, with branch survey offices in Manchester, Newcastle and Edinburgh.

The Water Pollution Research Laboratory, Watford, with a branch at Birmingham.

The Building Research Station, Watford.

The Forest Products Research Laboratory, Princes Risborough.

The Pest Infestation Laboratory, Slough

The Road Research Laboratory, Harmondsworth.

The third function of the Department was the scheme of grants, still in active operation, for the maintenance of post graduate students at the universities.

The last principal function was the startlingly new institution of a scheme for co-operative research associations, autonomous within their own industries which also financed them, with assistance by grants from the Department. It was originally expected, an expectation that did not generally materialize and has since been abandoned as an item of policy,[2] that the initial impetus would be sufficient and that many industries would later be both able and willing to carry on their co-operative ventures without government assistance Both interest and capital were to be expended, therefore, over a period of five or six years

Co-operative Research Associations

The war was having a considerable influence on the attitude of industry, and association for one purpose or another was in the air The suggestion of co-operative associations for research was not, therefore,

[1] *Scientific Research and Development*, 1944 Cmd 6514

[2] It was announced by Lord Balfour in 1928 that state aid to research associations should not cease with the exhaustion of the fund, but should be continued from the Department's annual vote from Parliament.

destined to fall on sterile ground. At the same time, it seemed likely that most of the existing trade associations were unsuited for conducting research but associations specifically for research could be formed either in connection with, or independent of, the trade associations. The means devised for this was the establishment, under the Companies Acts, of associations for research limited by guarantee of a nominal amount and working without profit. To this type of association the department was willing to make grants usually on a £ for £ basis and at the same time the contributions of industry were to be treated for taxation purposes as working expenses It will be seen that the incentive to the formation of such associations was considerable, so much so, that the suspicions of industry began to be aroused. It appeared possible that the Government was seeking some sort of technical control over industry and that the incentives provided were, in fact, a golden chain to this end.

The Department was therefore at pains to point out that, while some measure of control was necessary seeing that public funds were involved, the powers available to it would not be wrongly used. Three practical guarantees were given which have continued in operation since the earliest days. First, all possible help and advice would be afforded to associations that could be formed without calling upon Government financial aid. Second, any association could contract out of the Government scheme at any time. Third, grants made to associations would, in any case, be limited to a term of years, and it has been usual to work in quinquennia with each association since that day. It is evident that the fears of industry were stilled, for by 1918 the Board of Trade had issued licences to three Associations, the British Photographic Research Association, the British Scientific Instruments Research Association, and the Research Association for the Woollen and Worsted Industries, while no less than thirty industries were actively engaged in the preliminary moves for the formation of Associations.

To assist industry to appreciate the motives activating its work and the principles underlying the new movement as well as to simplify their deliberations, the Department issued a number of documents including notes for the guidance of would-be formers of research associations,[1] giving a statement of the conditions of the Government grant scheme. A model Memorandum of Association[2] was also drafted and circulated by the Department. A descriptive leaflet[3] in non-technical language explained the manner in which associations were expected to work. Experience has dictated various changes in these documents but in essentials they remain the same to-day as when they were first drafted. Indeed it is impossible not to be impressed by the skill and wisdom of

[1] *Conditions as to the Payment of Grant by the Committee of Council*, 1917

[2] *Draft Memorandum and Articles of Association*, 1917

[3] *The Government Scheme for Industrial Research*, 1917.

the initiation of this revolutionary incursion of Government into an uncharted field. The cautious, though not over-slow, methods by which the scheme was introduced was well warranted and too high praise cannot be given for the firm foundation upon which it was founded. Time and experience have added an embellishment here and removed

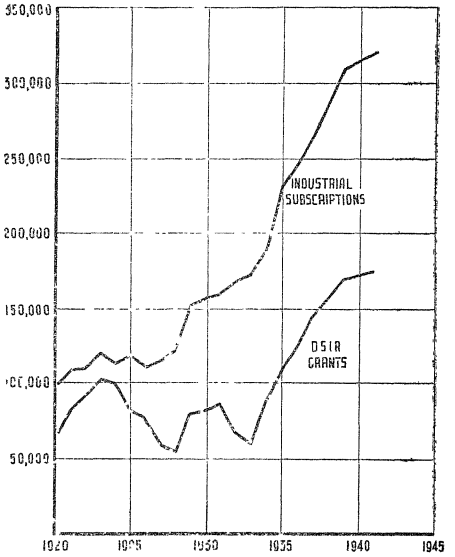


Fig 1.—Research Association Incomes, 1920-41.

an obstruction there, but the main structure of the original architects' scheme remains substantially as they first envisaged it.

The original 'million fund' was exhausted in 1932 at which time there were twenty research associations in active operation spending between them £235,000 a year of which £68,000 was contributed by the Department. At about the same time the Department, in common with other Government Departments, was instructed by the Treasury to curtail its expenditure drastically in view of the financial stress of

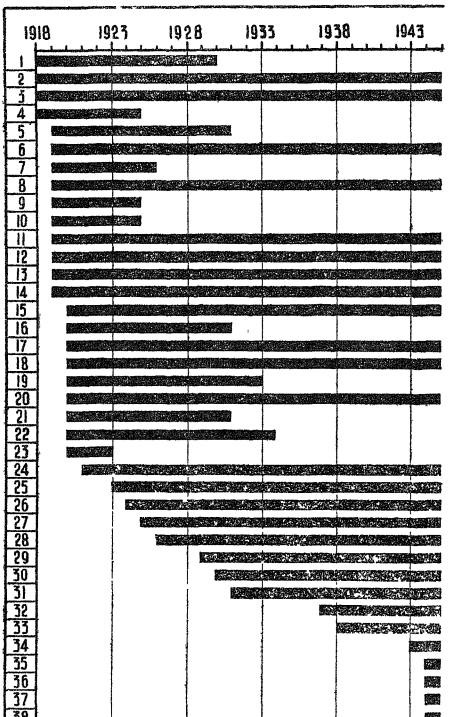


Fig 2 —Life Periods of Research Associations, 1918-45.

1. British Photographic Research Association.
2. British Scientific Instrument Research Association.
3. British Research Association for the Woollen & Worsted Industries.
4. British Portland Cement Research Association.
5. The Research Association of British Motor & Allied Manufacturers.
6. British Boot, Shoe & Allied Trades' Research Association.
7. British Sugar Research Association
8. British Cotton Industry Research Association.
9. British Iron Manufacturers' Research Association
10. Glass Research Association.
11. Linen Industry Research Association.
12. Research Association of British Rubber & Tyre Manufacturers.
13. British Association of Research for Cocoa, Chocolate, Sugar Confectionery & Jam Trades
14. British Non-Ferrous Metals Research Association.
15. British Refractories' Research Association
16. Scottish Shale Oil Scientific & Industrial Research Association.
17. British Launderers' Research Association.
18. British Leather Trades' Research Association.
19. British Cutlery Research Association.
20. British Electrical & Allied Industries' Research Association.
21. British Motor Cycle & Cycle Car Research Association.
22. British Silk Research Association.
23. British Music Industries' Research Association.
24. British Cast Iron Research Association.
25. Research Association of British Flour Millers.
26. British Colliery Owners' Research Association.
27. British Food Manufacturers' Research Association.
28. Research Association of British Paint, Colour & Varnish Manufacturers.
29. National Federation of Iron & Steel Manufacturers (Industrial Research Council).
30. Printing & Allied Trades' Research Association.
31. Institute of Automobile Engineers (Research & Standardization Committee).
32. British Pottery Research Association.
33. British Coal Utilization Research Association.
34. British Internal Combustion Engine Research Association.
35. British Shipbuilding Research Association.
36. Scottish Seaweed Research Association.
37. Parsons & Marine Engineering Turbine Research & Development Association.
38. British Paper Makers' Research Association.

the depression years. Figure 1 shows the reduction in grants to the research associations that became effective in 1932 and 1933. It is to the credit of industry and the energy of the research associations that even during this difficult period the industrial contributions to the co-operative associations continued to increase. To some extent this was due to a broadening of the basis of membership of some of the associations whereby big consumers of the industry's products became members and so, while benefiting directly as they had previously done indirectly, contributed to the financial stability of the organization. At the same time many of the research associations were operating on an extremely small budget. In 1933 the average expenditure of the associations was only £14,500 a year and this average included a few very large associations, so that the average for thirteen associations was less than £7,000 a year.

This scale of operations cannot be considered excessive for moderate sized individual companies and for co-operative research on an industry-wide basis it must be regarded as ludicrous Economy of finances and personnel by the co-operative scheme does not imply niggardliness on this grand scale and if there is any criticism of the effectiveness of the research association system the scale of finances in these critical years is a sufficient answer. It is inconceivable that a research association spending less than £30,000 to £50,000 a year should be even contemplated.

A review of the position, of the seriousness of which the Department was well aware, led to a drive being made in 1933 to increase the scale of operations and the situation had so far improved by 1939 that there were then twenty-one grant aided associations spending some £480,000 a year of which the Government contribution accounted for £170,000. The average had thus been raised to nearly £23,000 but this still included a few outstandingly large associations of which two had incomes in excess of £100,000 a year.

The majority of research associations raise their industrial contributions by means of subscriptions from members to whom the greater part of their research results are confined. Membership is voluntary, and much time and energy must be spent each year in convincing members, or potential members, of the value of the association and in collecting the subscriptions. A more serious drawback is the encouragement of a tendency to indulge in a high proportion of *ad hoc* and immediately useful small investigations to the detriment of the long term researches for which the research associations are most suited. In a very few cases this is mitigated by the contribution of the industrial income, either wholly or in part, in lump sums by one or more trade federations. In such cases all the members of the federations concerned become automatically members of the research association. When financed in this way the research associations become in effect corporate co-operative associations.

It was suggested so long ago as 1927 that an Enabling Bill should be passed, making it possible for any industry that could satisfy the Board of Trade that a high proportion of its members, say 70 per cent., desired a levy for research purposes, to claim an order in Council making the levy compulsory upon the whole industry. The suggestion did not, however, receive the general support of industry and was not pursued. It was raised again in 1933 with the same result. The industrial income of one association only is now provided in this way, although voluntary levies for the support of research have been agreed in some industries. The Cotton Industry Enabling Bill of 1939 provided for a statutory levy on bale cotton entering the country, and when this was replaced by the war time Act of 1940, the provision of funds for research was safeguarded. Voluntary levies have been agreed of 1s. 10d. per ton on coal output to finance the British Coal Utilization Research Association, and of 1d. per bale on imported wool for the support of the Wool Industries' Research Association. Levies have also been agreed upon for the financing of the British Pottery Research Association and the British Refractories' Research Association [1]

Not all the Associations that have been formed have been equally successful. Figure 2 shows diagrammatically the life of each organization that has come into operation under the Government scheme. Twenty-three Associations were formed in the first three years from the introduction of the scheme and ten of these had ceased operations for one reason or another by 1934. After the initial spate, associations were formed at a more steady rate, ten coming into operation at fairly regular intervals during the next eighteen years although there was a pronounced hiatus from 1931 to 1937 when industry was presumably recovering from the set-backs of the depression years and proceeding cautiously in consequence.

The prospect first, and later the actuality of war, then put an end to the formation of new associations until 1943 when, with improved national fortunes and a growing national interest in the fruits of research consequent upon consistent reports of the part played by scientific discovery and invention in the approaching victory, a new spirit of research enterprise manifested itself This was fostered by the tone of speeches on the need for scientific research in the House of Commons during 1944, by the improved financial conditions that the Department of Scientific and Industrial Research was empowered to grant, and by the impact of the Excess Profits Tax coupled, particularly, with the provision of the Finance Act of 1944 for the ranking of research expenditure,

[1] An Industrial Research Bill introduced into the House of Lords in October, 1945, provides that a research association may be created for each industry and financed by a levy not exceeding 1 per cent of each contributor's annual turnover or revenue. The Bill provides also that schemes for the formation of research associations as approved by the Board of Trade may be the subject of polls by the Board, and if in any industry a number representing 75 per cent. of the annual turnover or revenue, vote in favour of the scheme, an association will be formed.

including contributions to co-operative research associations, whether for capital or current expenditure, as expenses allowable for deduction when computing taxation. In consequence of the enthusiasm thus engendered, four new associations were formed during 1944 while a further three, for the radio, jute and rayon industries respectively, were proposed but not formally incorporated. There were, therefore, at the end of 1944 no less than twenty-seven associations in active operation and at least three in active process of formation.

Other Co-operative Research Ventures

Although the Department of Scientific and Industrial Research has been the predominating influence in the co-operative research movement in Great Britain, it should not be thought that there have been no other co-operative efforts. In the first place there have been a few co-operative organizations which have carried out their work without financial assistance from the Department, without the formation of central research associations and without the merging thus implied of commercial interests. The Therapeutic Research Corporation of Great Britain Ltd. was formed in 1941 by the joint action of a number of fine chemical and pharmaceutical manufacturers.[1] The directors of the research departments of the firms involved constitute a panel which draws up the programme of work, and any products of therapeutic value evolved by the Corporation are to be marketed by all the firms under a common name. The Steel industry also has shown a genuine co-operative spirit in the Iron and Steel Industrial Research Council which uses the works of member firms in which to carry out research. The firms concerned thus co-operate actively in the projects assigned to them and often bear a large proportion of the cost of the researches allotted to them, thereby relieving the expenses of the Council.

With or without government assistance, co-operative research in Great Britain has followed closely a single line of development. There is, for example, no institution in this country based upon the fellowship or donor plan as operated on a considerable scale in the United States of America by organizations such as the Mellon Institute for Industrial Research, nor have the universities and technical colleges developed research foundations like those of some of the great American Universities. The sphere of universities and technical colleges in this great work, although important, is fraught with difficulty. The two problems of academic freedom and commercial secrecy are hard to reconcile and the most usual direct contribution of the universities to industry is restricted to consultative work on the part of the academic staff. Nevertheless, they have played an outstanding part in British industrial development. In addition to the extension of knowledge emanating from the university laboratories and of vast potential value to industry, much

[1]Boots Pure Drug Co Ltd., British Drug Houses Ltd., Glaxo Laboratories Ltd., May and Baker Ltd, Wellcome Foundation Ltd.

has been done by them through special technological departments closely related to local industries. At almost all the universities there are now highly developed departments that have contributed greatly and directly to industrial progress—at Sheffield the Metallurgical Department and the Glass Institute, established in 1916 with the assistance of the Department of Scientific and Industrial Research; at Leeds the Departments of Tinctorial Chemistry, Fuel Industries, Leather, and Textile Technology; at Birmingham, the Departments of Mining and Brewing; the Dairy Research Institute attached to the University of Reading; and the Long Ashton Agricultural Research Institute and the Canning Research Laboratory at Chipping Camden attached to the University of Bristol. Examination of the early researches aided by the Department reveals that other than work carried out at the National Physical Laboratory, all were established in college laboratories.

Perhaps the most interesting, and potentially the most valuable, departure from the standard pattern occurred in 1922 when an attempt was made to establish industrial research fellowships at the University of Bristol on lines that have since become familiar in the United States. The Colston Research Fellowships, as they were named, were originated by the Colston Research Society, a voluntary association of business men interested in the promotion of research in the University. The Society continues to function, and the University's researches benefit annually from its activities, but in 1922 the then President set himself not only to raise money for research in the University but also to bring local industrialists into more direct contact with it than hitherto and to combine the advantages of a business proposition to them with the benefit of an element of practicality in the University's work. It was an attempt to reconcile academic long-range research with the industrialist's impatience for results.

The Colston Research Fellowships of a value of £150 were to be awarded annually for post-graduate work to students of the University, and the money was to be furnished by local firms who could earmark the Fellowship known by their names for particular faculties, or particular branches of research or even for particular persons. In return they were to have access to the research work and to receive its results twelve months prior to any publication. In the year 1922–23 six firms became donors of Fellowships. Two of them ceased their donations after the first year, three Fellowships remained in operation until 1924 and two continued until 1926. No fresh donors were forthcoming after the original six.

It is not easy to see why so promising an experiment was abandoned. The lack of experience, both of the sponsors and the University, that would have enabled them to extract the full benefits from the scheme may be held accountable in part, as may also its early ambitious nature which contrasted with the mechanical limitations imposed by the conditions of award which, by restricting the choice of candidates,

made it difficult to find for each Fellowship the right combination of candidate and subject. It is moreover possible that the value of the Fellowships was insufficient to attract graduates of the highest calibre. There is little doubt that a similar scheme could, in the light of subsequent experience, be made to function satisfactorily. There have indeed been many grants since then made to the Universities by great concerns, particularly for work of a fundamental character. Imperial Chemical Industries Ltd., which has been foremost in this type of co-operation between industry and universities, surpassed all its previous interests by the establishment in 1944 of eighty fellowships in different branches of science, tenable in nine British universities, of an average value of £600 a year.

It is evident that the co-operative research net has been thrown widely, if shallowly, in all but the research association waters. So intimately intermingled are the different methods, that it would be impossible to construct a coherent account by methods of research. Moreover, co-operative research has become so woven into the fabric of industrial and national life that it seems preferable to try to see it against the background of industrial influences and this is illustrated in relation to some of our great industries in the following brief descriptions.

Agriculture

Agriculture,[1] by whatever yardstick it is measured, must be counted a major industry. It is the primary industry of all communities and whether considered in the light of the basic importance of its products, or the employment it provides both directly and indirectly, or the invested capital it represents, it exhibits all the characteristics also of a great one. The importance of the industry's products may be judged in the light of Sir Harold Hartley's statement that about 88 per cent. of the world's agricultural products before the war was used for food, about 8 per cent. for textiles and 4 per cent. for other industries. The number of workers in agriculture in England and Wales was in excess of 600,000 and the turnover of British agriculture was, according to the Minister of Agriculture, in the neighbourhood of £600,000,000 in 1943.

The annual net value of the output of British farm workers before the war was £200, while that of German workers was only £70. Not all of this was accounted for by differences in efficiency but while on English yields, 1·6 acres was considered necessary to feed the average Englishman, at least 2 acres was required on the basis of yields abroad. During the war the efficiency of British farming has increased by leaps and bounds. Whereas in 1939 we were 40 per cent. self-sufficient in foods we are now 70 per cent., and this has been achieved, not only by large increases in the acreage of arable land, but also in increased productivity and more efficient methods. It is estimated that the output

[1] A full account of the present position of agricultural research is given in *Agricultural Research in Great Britain*, 1943, Cmd. 6421.

per man, measured in food values, has increased by 60 per cent. during the war period.

It is to the large scale application of the results of agricultural science that these improvements are due, but research in agriculture is not a simple procedure. In the nature of the case, only co-operative research can produce the desired results. The industry is nation-wide and controlled by a great many private individuals to the extent that some 40 per cent. of the total agricultural land is farmed by owner-occupiers. The majority of the farms are too small to consider independent expenditure on any kind of systematic investigatory work—half the land is broken up into farms of less than 150 acres. Some large-scale research is being done by suppliers such as the Imperial Chemical Industries at its station at Jealott's Hill, Berkshire, but in the main, agricultural research is a national problem

It is not surprising, therefore, to find that in Great Britain as elsewhere agricultural research is chiefly directed and financed by the Government. The Ministry of Agriculture and Fisheries is responsible for the application of scientific methods to farming, although it is concerned also with the winning of new knowledge and the Department of Agriculture for Scotland has similar responsibilities. To further their work these two government departments have recently set up, respectively, the Agricultural Improvement Councils for England and Wales, and for Scotland. The main responsibility for agricultural research is shouldered by the Agricultural Research Council and this organization is concerned chiefly with the financing and co-ordination of the work of the agricultural research institutes, a term widely used to cover not only large experiment stations, but also special units in Universities and other Institutions.

The Agricultural research institutes fall into three classes:—

(*a*) Those under the direct control of the Ministry of Agriculture and Fisheries.[1]

(*b*) Those under the direct control of the Agricultural Research Council.[2]

(*c*) Those financed wholly or partly by the Ministry of Agriculture, of the Department of Agriculture for Scotland Grants for this purpose are paid from the Development Fund on the recommendation of the Commissioners under a scheme framed in 1911 for

[1]These comprise
The Veterinary Laboratory, Weybridge
The Foot and Mouth Disease Research Station, Purbright.
The Plant Pathological Laboratory, Harpenden
The National Institute of Agricultural Engineering, Askham Bryan
The Grassland Improvement Station, Dodwell Drayton.

[2]These comprise
The Field Experiment Station, Compton.
The Unit of Animal Physiology, Cambridge.
The Unit of Soil Enzyme Chemistry, Rothamsted.

the establishment of such institutes. There are now twenty-two agricultural research institutes,[1] covering almost every branch of agricultural science, including soil research, plant and animal nutrition, plant and animal breeding, dairying and agricultural economics. Their work is co-ordinated by the Agricultural Research Council to which they make an annual report on the research programmes and their estimated cost.

Beyond considering the relation of the researches in different places to each other and advising on the allocation of funds, the Council does not directly control the institutes, many of which have their own governing bodies and each of which is encouraged to maintain its own individuality and to make its own contact with agricultural interests related to its special field of studies. Many of the agricultural research institutes have commenced independently of government support, having been established to meet particular needs, either in a specialist subject such as soil chemistry, or in specialist products such as horticulture or glasshouse crops. The development of one such institute may serve to illustrate the method by which agricultural research in Great Britain has progressed.

The Rothamsted Experimental Station was born in 1843 when John Bennet Lawes took as his assistant Joseph Henry Gilbert for the purpose of extending the agricultural investigations which he was conducting on his estate at Rothamsted. Lawes had already found that superphosphate of lime was beneficial to plants and had set up a factory to manufacture it. Lawes and Gilbert initiated field experiments which have continued from year to year until now. Their main interest was the investigation of plant nutrition and their work on this laid the foundations of modern manuring practice. For nearly sixty

[1] These comprise:
Rothamsted Experimental Station, Harpenden
Macauley Institute for Soil Research, Aberdeen
Long Ashton Research Station, Bristol
East Malling Research Station, Kent
Horticultural Research Station, Cambridge
Experimental and Research Station (for glass-house crops) Cheshunt.
Plant Breeding Institute, Cambridge
Welsh Plant Breeding Station, Aberystwyth
John Innes Horticultural Institution, Merton
Scottish Society for Research in Plant Breeding, Edinburgh.
Research Institute in Plant Physiology, Imperial College of Science and Technology, London.
Plant Virus Research Station, Cambridge
Institute of Animal Pathology, Cambridge.
Research Institute in Animal Pathology, Royal Veterinary College, Streatley.
Animal Diseases Research Association, Edinburgh.
Animal Nutrition Institute, Cambridge.
Rowett Research Institute, Aberdeen
National Institute for Research in Dairying, Reading
Hannah Dairy Research Institute, Ayrshire
Institute of Agricultural Parasitology, St Albans
Agricultural Economics' Research Institute, Oxford
Institute of Animal Genetics, Edinburgh

years Lawes bore the whole cost of the experiments. Their value was early recognized by local farmers who, in 1853, opened a subscription list to present Lawes with a testimonial. The money so collected was used to build a laboratory to replace the barn in which the early experimental work had been carried out. To ensure the continuity of the work, which was one of its essential features, Lawes established a Trust Fund in 1889 with an endowment of £100,000. The Lawes Agricultural Trust and its management Committee became, and still are, the governing body of the experiment station.

Sir John Lawes and Sir Joseph Gilbert, as they had become, died within a year of each other in 1900 and 1901, and were succeeded in the direction of the Station by Dr. A. D. (later Sir Daniel) Hall. The increased expenditure of the growing institute was met to some extent, after 1911, by funds from the Development Commission. After nearly seventy years, therefore, public funds were for the first time made available for the support of the Rothamsted work and the station was made responsible for researches in the twin subjects of plant nutrition and soil chemistry. Other agricultural institutes were similarly assisted and at each the aim was the same—long range research without concern for its immediate applicability.

With the introduction of State assistance there came a new emphasis, for the whole of the original work of Lawes and Gilbert had been strictly utilitarian. The annual 'grant-in-aid' from the Development Commission was based on the estimated expenditure but did not cover the whole of it The balance was to be raised by the Station. Similarly, assistance was forthcoming for approved capital expenditure, but a balance had always to be found. For raising the additional sums required, an independent organization, known as the Society for Extending the Rothamsted Experiments, was established. The Rothamsted Experimental Station thus became a true co-operative research enterprise.

The change in its financial arrangements gave a fillip to the work at Rothamsted which, in the later years of Lawes and Gilbert, had become somewhat moribund. A second fillip was given to agriculture as to other industries by the outbreak of war in 1914. So impressed was the farming community by the need for the application of science to agriculture and by the assistance received from the agricultural research institutes, that when the Corn Production Act was repealed in 1926 the farmers asked that £1,000,000 should be set aside to finance additional research.

During this period the Rothamsted Station was steadily expanding. Departments of Plant Pathology, Statistics, Entomology and Insecticides were added to the already existing Departments of Chemistry, Physics, Botany and Bacteriology. The Woburn Experimental Station was acquired from the Royal Agricultural Society and the Imperial Bureau of Soil Science was established at Rothamsted. In 1936 the experimental farm, previously a yearly tenancy, was purchased for £35,000. New

laboratories, glass-houses and extensions to the out-buildings have been completed and further capital expenditure is planned for the post-war period. From 1912, the year after public funds were added to its income, to 1941, the capital expenditure at Rothamsted has exceeded £200,000 and the annual expenditure has risen from about £5,500 to almost £46,000, while in the same period the scientific staff has increased from a mere five to more than fifty.

The story of Rothamsted is the story of the strenuous and successful efforts of individuals backed, at first spasmodically, and later consistently, by co-operative support. It is a story that in its essentials could be repeated for other agricultural research stations and that affords convincing evidence of the value of co-operation in research. It may be doubted whether, even now, sufficient funds are available for the prosecution of agricultural research on the scale necessary to the welfare of a country situated as Great Britain. How little is needed may be reckoned from consideration of the figure of annual turnover given earlier. If one penny in the pound of this turnover were levied for the support of co-operative research it would produce an annual income of £2,500,000.

It is by intensive research and its corollary, intensive application to practical farming, that the conditions of farmers and farmhands will be improved and the public benefited by the ample supply of better produce at no greater cost. In farming, as in other industries, the answer to higher wages is not more arduous or longer work but the provision of more capital per worker so that output is increased and standardized. "Gone are the days of hard slogging, with poor meals and poorer accommodation, and in their place is work calling for a good head, an agile arm and a true eye."[1]

The importance of agriculture is not confined to food crops. The Forestry Commission maintains a research team engaged chiefly in field studies and also makes grants to universities and research institutes for work requiring specialized information, techniques or equipment. It is expected that, with the end of the war, forestry research will be considerably extended.[2] Two laboratories of the Department of Scientific and Industrial Research—The Pest Infestation Laboratory and the Forest Products Research Laboratory—also carry out work that is closely related and invaluable to agriculture although their main fields, like those of the laboratories controlled by the Food Investigation Board, are concerned with post-agricultural processes, namely the preservation, storage and transport of agricultural products. The Linen Industry Research Association also carries on extensive agricultural research into the growing of flax and this work, considerably developed with the assistance of the Ministry of Supply, was of the utmost value during the war.

There can be no question that the future of agricultural research will be based on a wider field of application than ever before Agri-

[1] *Spring Onions*, Duncan McGuffie, 1942.

[2] *See* Cmd. 6447. H.M.S.O., 1943.

culture will be expected to supply more and more of the raw materials for industry. The new textile fibres such as rayon, derived principally from wood pulp have, for example, an almost inexhaustible and replenishable source of raw material. Oils, resins, and perfumes may be directly extracted but the industrial utilization of agricultural products such as grains, straw and potatoes, particularly by the newer fermentation industries, opens up vast unexploited possibilities for future generations. The utilization of industrial and national wastes—sewage, town refuse, effluents, etc.—for agricultural enrichment will provide food for research for a long period to come and the use of agricultural products as a source of power to replace the rapidly diminishing stores of coal and oil must also be envisaged.

Food

Research in food, its transport, preservation and efficient use is a logical corollary of research in agriculture. A healthy and efficient agricultural economy is valueless if its products are subsequently wasted by inefficient handling and utilization. The study of the provision of both quantity and quality in food is of particular importance to Great Britain Its every interest and very existence are bound up with the problem of food. As an island kingdom it found to its cost during the first world war the dependence it exercised on imported food As an industrialized nation its millions of factory workers are dependent upon the regular and unfailing supply of healthgiving foods without the necessity of expending time and labour on their production. As a maritime race, the health of its sailors, the comfort of its passengers and the whole structure of its modern shipping interests hang upon the successful transition from 'salt horse' to fresh food at sea.

Before the second world war Great Britain imported between £400,000,000 and £600,000,000 worth of food every year. Even in the depression period of 1931 we spent £417,000,000 on food, drink and tobacco. For four days out of every five we bought our food abroad, and Sir John Russell estimated that with all the improvement in domestic production we shall still need to import some 50 per cent. of our food after the war. The best use of this precious and expensive commodity is therefore a national problem.

Loss of valuable food material by deterioration goes on at every stage, in the field, in transport, in storage, in the markets, the shops and the homes And all this wasted food has to be paid for equally with the good food that reaches our tables. Equally important is the quality of the food. For this, or any other, country to play its part in the modern world, its food must be not only adequate in quantity but satisfactory in quality High quality and the prevention of waste by deterioration must therefore be linked in any extensive programme of food research.

With these problems in mind and fear for the nation's larder in

their hearts, the first approach to the Government for a national policy on food research was made in 1917 by a deputation from the Ice & Cold Storage Association. As a result of their representations the Cold Storage Research Board was set up by the Department of Scientific & Industrial Research to organize and control research into the problems of the preservation of food by cold and other means. It was soon realized that the problems extended beyond the simple use of low temperatures as a preservative, and in 1918 the terms of reference were changed to the organization and control of "research into the preparation and preservation of food" and the name was altered to the Food Investigation Board. The Board's interest in refrigeration was, however, maintained, as might be expected, since it is the most commonly used method for the preservation of food. On ships, in trains, in great warehouses there are thousands of cold storage depots without which Britain could not maintain its great industrial population.

It is well to remember that refrigeration did not just happen. Before the days of State intervention or co-operative research enterprise, pure and applied scientific research had produced the results upon which the cold storage industry was based. The ancients were aware of the value of ice as a preservative, but it was not until Joseph Black formulated the theory of latent heat that the scientific basis was laid upon which an industry could be built. Lord Kelvin, about 1850, established the thermodynamic principles underlying the use of volatile liquids as refrigeration liquids and from that point progress became rapid. Some earlier attempts to produce refrigerators had been partially successful, but with the work of Carré, Linde and Windhausen and the introduction of ammonia and carbon dioxide for use in the machine, refrigeration became a practical and economic proposition.

The first perishable food to be transported over a long distance was meat. In 1877 a cargo was brought from the Argentine in 110 days, with some success, in an ammonia refrigerator. In 1879 the Anchor line installed a refrigerator in one of their ships and in 1880 they successfully transported a cargo of meat from Australia. Expansion of trade by the new method was rapid. By 1901, 150,000 tons of meat were imported in a year from the United States alone and by 1939, 90,000 tons a month were imported. The success with meat was repeated with other foods. An entirely new trade in fruit from Australia, New Zealand and South Africa came into existence. The cold storage industry is as vital to the successful economy of these countries as to that of Great Britain.

But refrigeration engineering is not the whole story. Many of the foods that must be preserved are living tissues which, if they are to be kept successfully, must be kept alive. It was fundamental scientific research that laid the foundation of the refrigeration industry and it was fundamental thinking that led to the next great advance. This came with the setting up of the Food Investigation Board which adopted

the policy from the beginning of its existence of building up by slow but certain methods a science of food preservation. The change of outlook that led to the discovery of new basic principles is best expressed in the words of Sir William Hardy, the first Director of Food Investigation, who said: "The industry is essentially a biological industry. Biological thought and biological research fix the conditions necessary for successful storage, and to the cold storage engineer is left the duty of realizing those conditions in practice. Logically, biology has precedence". It is the last sentence that is full of significance, for it foreshadows the change of front in the attack. With the change in its name the Board changed its policy. From being a centre of refrigeration engineering research it became a centre of biological research. Biologists and bacteriologists became as important as engineers.

The success of the new approach can now be judged in the light of the progress in the three main problems with which the Board was originally faced. These were, the preservation of fruit, the cold storage of which was far from successful; the transport of beef more satisfactorily than by freezing, and the storage of fish. All three problems have been satisfactorily solved and all by the methods of applied biology. The first was solved by the introduction of gas storage—a development worked out entirely in the Board's laboratories at Cambridge and Ditton. From about 1930 when there were no gas stores, to the beginning of the war, more than three million cubic feet of gas storage space had been provided Up to 1933 the distant Dominions sent their meat to Great Britain in the frozen state. The chilled variety, which is the more esteemed, could be guaranteed for not more than 28 days. The recognition of the cause of the deterioration led to the introduction of the chilled process combined with carbon dioxide storage and in June, 1933, the first consignment of New Zealand chilled beef was landed at Southampton. Fish presents an even bigger problem Trawlers remain at sea for considerable periods and the normal method of storage in ice keeps the fish fresh for only ten to twelve days. Brine freezing has solved the problem of the storage of fish and experiments are recorded at the Torry Research Station of fish being maintained by this method in a fresh condition for more than two years

Although the available resources were first concentrated upon the problems involved in getting fresh food from the producer to the consumer, the problems involved in the processing of food have not been overlooked The Low Temperature Research Station has conducted researches on bacon and at a later date the Board became interested in the Fruit and Vegetable Preservation Research Station at Chipping Campden This laboratory, run in conjunction with the University of Bristol, was originally fostered by the Ministry of Agriculture and Fisheries. The Station was a combined research and teaching establishment which rapidly developed a reputation for its work relating

to canning From being an occasional technical guide it soon became a centre of the canning industry's interest, and firms commenced to support it in the same manner as in other industries they supported co-operative research organizations The Campden Research Station, therefore, became the unofficial research association of the canning industry. It was at this stage of its development that the Department of Scientific and Industrial Research realized that the interests of the Station were included with those of the Food Investigation Board. This realization led to the view that other such stations might be necessary for other food processing industries and the Board's policy was extended to cover the supervision of all such work as might, in their view, be in the national interest

Although it is a national problem, not all food research is carried on by the community co-operative system There are also genuine co-operative research associations interested in the food industry. The Research Association of British Flour Millers was established in 1923 and in 1938 had an income of £13,000. The British Association of Research for the Cocoa, Chocolate, Sugar Confectionery and Jam Trades established in 1919, and with an income of £12,000 in 1938, is closely associated (to the extent of sharing laboratory accommodation and being under the same director), with the British Food Manufacturers' Research Association established in 1926 and having an income in 1938 of about £5,000.

Corporate co-operative research is also represented in the industry by the Research Fund Committee of the Institute of Brewing. The expenditure of the Institute on research in 1943 was nearly £8,500, mainly on its own laboratories in the University of Birmingham and the Manchester College of Technology, but also on grants to various colleges and research stations for extramural research on problems of interest to the brewing industry. In particular the Institute has fostered work on the growing of hops, the study of yeast and the fermentation process, and the germination of barley.

The food industry has also provided one of the most striking examples of co-operative research yet seen. It was at one time widely thought that co-operation in such schemes could be effective only between members of the same group, that is to say, between producers or consumers or suppliers of services but not between the groups whose commercial interests might be expected to intervene in any scheme for co-operation in technical matters. This view is not now so widely held as it once was and the problem of the infestation of grain by insects has shown that widely different sections of the industrial community can combine for an attack upon a problem in which all have a stake.

Work on the problem of weevils in grain was initiated by the London and North Eastern Railway Company with the setting up of an informal committee in 1937. By the spring of 1938 sufficient progress had been

made for a meeting of all the interested parties with the Department of Scientific and Industrial Research to decide upon the organization of a plan of campaign. In pursuance of its usual practice the Department promised its assistance if a sum of £1,200 was raised from industry as a contribution to the expense of an initial survey of the problem. A Standing Conference was set up and in May of the same year work was commenced at the Stored Products Laboratory of the Imperial College of Science and Technology Support for the project and representatives on the Standing Conference came from perhaps the widest interests ever to collaborate in research for the solution of a specific problem. They included farmers, corn merchants, flour millers, maltsters, brewers, cattle food traders, railway companies, lightermen, wharfingers and port authorities The scope and importance of the work has grown and its national character has since been recognized by the setting up under the Department's immediate responsibility of the Pest Infestation Laboratory.

Fuel and Power

If agriculture is the primary industry of all communities and food the essential one for an island race, the key to the new world is power, and power with few exceptions such as tidal or water power, depends on fuel.[1] The world was transformed in 1769 by Watt's conversion of the steam pumping engine to an efficient power unit. Coal then became the 'black gold' upon which the British industrial fortune was built But the value of power was such that incessant search for new forms of power or new sources of fuel went on. Inflammable gas from coal was well known and in 1812 the Gas Light and Coke Company was incorporated for the purpose of supplying coal gas to London. In 1831, Faraday discovered that the movement of a magnetic field near a conductor produced a current. Nobody could then have predicted that from these elementary experiments in induction would spring the great electrical industry with its generators, motors and transformers capable of producing and handling millions of horse-power. In 1859, Colonel Drake discovered oil in Pennsylvania and so set on foot one of the world's great industries and a new source of power.

Improvements in the use of fuel and increasing efficiency in the development of power have been the watchwords of the industrial age and have expanded the use of fuel to unimagined proportions. The productivity of the age has been determined by the capital assistance given to the worker by a power supply beyond the competition of human muscles, through machines and tools dependent upon power, by transport facilities undreamt of before power came into its own, and by lighting that has turned night into day. It was the acceptance and avid utilization of power that brought Great Britain the

[1]The possibilities inherent in atomic energy have been strikingly demonstrated since this was written.

lead in industry and to maintain the lead, research into the utilization of fuel and power for the increase of capital assistance is an essential.

Industrial civilization is based essentially upon the utilization of capital resources in the shape of fuel and if we must live on capital it must be made to last as long as possible Research on fuel is, therefore, doubly necessary. But fuel is a subject of interest to a wide variety of users. It is a community interest and as a result, fuel research takes its place with the select few that are fit subjects for Government action on a large scale.

In Great Britain more limited co-operative research organizations have also come into existence. Fuel and power research in this country is now carried out co-operatively at the Fuel Research Station of the Department of Scientific and Industrial Research, by the British Colliery Owners' Research Association, the British Coal Utilization Research Association, the Gas Research Board, the Electrical and Allied Industries' Research Association, and as part of the programme of research of such related organizations as the Iron and Steel Industrial Research Council which studies, among other subjects, the use of coke for metallurgical processes. The Standing Consultative Conference on Fuel Research ensures that the whole field of fuel production, use and economy is adequately covered.

The question of research on coal and its uses came before the Advisory Council of Scientific and Industrial Research early in 1916, and as a result of a memorandum on the subject prepared in May of that year the Reconstruction Committee in July appointed a sub-committee to consider and report on coal conservation. A conference between the Council and the Reconstruction Committee led to an agreement that the former should be responsible for the organization and conduct of all research on coal by whichever body it had been initiated At the same time, the British Association for the Advancement of Science had a committee working on fuel economy and an agreement was reached that the Council should cover this field also and should set up a Standing Committee on Fuel. In November, 1916, a small sub-committee commenced to consider ways and means of carrying into effect the desires implicit in the work of the earlier committees This sub-committee recommended a form of machinery which, after approval by the Government, resulted in the establishment of the Fuel Research Board with a Director immediately responsible to the Lord President.

The requirements of the Board, of laboratories suited to its work, was met in 1918 by the building, on a site at East Greenwich, of a Fuel Research Station The first proposals for work resulted in a plan to survey the coal resources, classifying them and ascertaining their most efficient industrial uses. This work has been continued since and the coal survey has become a large and permanent section of the Board's work. The work has not, however, been confined to coal. Even in

the early days, proposals for the utilization of peat were under consideration by the Board, and liaison was made with the Board of Trade on the question of fixing standards of quality for town's gas. Atmospheric pollution and safety in mines have also been subjects that have received the constant attention of the Board. As an adviser to government departments, including the Services on fuel problems, the Board has had to cover a wide field of investigation into the nature, use and production of fuels of all kinds. It might be expected, therefore, that there would be room for specialist considerations for particular fuels and other research organizations have come into existence to deal independently with their own fields

Co-operative research in the coal-gas industry is of long standing. Technical progress in the industry derives from three sources, the gas undertakings, the contractors and manufacturers of apparatus for the production, distribution and use of gas, and joint research programmes supported by the whole industry. In the early stages of the present century new ideas were beginning to emerge and the industry, boldly determined to take advantage of them, undertook joint scientific investigation of its problems. Throughout the ensuing period the University of Leeds has been closely associated with the prosecution of research on the problems of the gas industry

The Joint Research Committee of the University and the Institutions of Gas Engineers continued in active operation until 1939, when the Gas Research Board was formed, and it became a joint committee of the Board and the University of Leeds. The Gas Research Board then became associated with the Department of Scientific and Industrial Research, thereby coming within the national scheme of industrial research. This arrangement is not a usual one in Great Britain where the co-operative research organizations are, as a rule, independent. Association with a University is more usual, however, in the United States where large co-operative research establishments, usually of the fellowship type, are frequently both located at, and associated with, the University. One advantage claimed for this method, which has been exploited by the gas industry, is that the University association enables the research to be carried on in an atmosphere of academic teaching where the training of men can be combined with the conduct of research.

Research has piled up during the years with more and more ambitious programmes aiming at the solution of such problems as the complete gasification of coal, the catalytic synthesis of hydrocarbons from carbon monoxide and hydrogen to utilize the coal with the greatest efficiency, and the development of infra-red drying by gas heated sources to extend the uses of the product.

The coal industry is the mainspring of the fuel and power industries in Great Britain. In 1932, the Coal Utilization Council was formed by joint action between the coal producers and the distributors. The

object of the association was to promote the better use of coal and one part of its programme required the prosecution of research into its efficient utilization. For this purpose the collaboration of the coal-burning appliance makers was needed, and steps were therefore taken to form the Coal Burning Appliance Makers' Association. This association was later converted to the Combustion Appliance Makers' Association which, in 1936, set up a research department with financial assistance from the coal industry

The small department soon justified itself and merited expansion, and in 1937 plans were laid before the Mining Association of Great Britain for the establishment of a permanent research organization that would conform to the principles adopted by the Department of Scientific and Industrial Research and with the latter's financial assistance its expenditure was raised from £5,000 a year to £20,000 a year. The Combustion Appliance Makers' Association had recommended at a conference in April that expenditure up to £500,000 a year on research directed to improvements in the methods of burning solid fuel would be justified and, in October of the same year at the Third National Coal Convention at Harrogate, definite plans for a research association were outlined. The coal industry had started out on co-operative research and by mid-1938 the new organization, known as the British Coal Utilization Research Association, had been registered by the Board of Trade.

The B.C.U.R.A. is remarkable for more than one reason. It represents a co-operative venture on the part of producers and users which is unusual. It is obvious that research carried out by producers of a commodity must usually benefit the users, but is not usual for the two parties to ally themselves in the carrying through of their project. The B C.U.R A. coming later to the scene was the first to recognize the principle boldly. The Mining Association of Great Britain and the Combustion Appliance Makers' Association are represented equally on the Council of the Research Association. Other organizations represented on the Council include the Water Tube Boiler Makers' Association, the Chamber of Coal Traders and the Co-operative Union, while the Mineworkers' Federation also have two representatives on the Council.

The Association is remarkable also for the speed of its growth and the adequate provision of its resources. At the end of 1942 the Mining Association agreed to a levy of 1s. 10d. per ton on the output of coal —a step calculated to bring in £80,000 to £100,000 a year. The Coal distribution and other interests now associated with the venture agreed to play their part on a similar scale and the Department of Scientific and Industrial Research, recognizing the urgency behind these terms, offered a grant of £50,000 per annum if the industrial income reached £150,000 per annum. In eight years, research for, and by the coal industry, as gauged by its income shown in the following table, has pro-

gressed until it has become the largest co-operative research association in the country.

	Year	*Income* (£)
C.A.M.A. Research Department	1936	2,000
	1937	6,000
B.C.U.R.A.	1938	25,000
	1939	31,000
	1940	32,000
	1941	36,000
	1942	75,000
	1943	170,000

The Association's premises were in West Brompton. These were partly destroyed by enemy action and the work was moved to a new site at Coombe Springs, Kingston. By 1942, there was a staff of 200 persons working in nine separate establishments. This difficult and inefficient arrangement is a wartime expedient and it is hoped that all the activities will later be co-ordinated in a single station. For this purpose a site of 20 acres has been acquired at Leatherhead where common facilities will be shared with other research associations to provide an 'Industrial University' and where it is intended to erect a new research station for the coal producing and consuming industries.

Not only is the problem of the domestic utilization of coal being tackled but its industrial use is being systematically examined by projects such as the grinding of coal and the use of pulverized fuel, combustion in fuel beds, steam engineering. Its use as a basis for the chemical industry is also to the fore in researches which cover the production of liquid fuels and chemical products. In 1911 the liquid products produced by the carbonization of coal exceeded the imports of petroleum products. The internal combustion engine raised the requirement of liquid fuel above what the coal by-products industries could supply. Before the war some two million tons of coal tar were produced annually. A large proportion was used for road surfacing and the remainder distilled to provide naphtha, creosote and other products for chemical industry. The contribution to the oil market was small. Coke ovens were finding it economic to recover the greater part of their benzol, but gas works only about 50 per cent. The contribution from these sources could offset imported supplies to a great extent and correspondingly enhance the value of our coal.

The growing importance of coal for the provision of liquid fuels arises from the increasing use of the latter and the feared disparity between supply and demand. Oil is a prime essential for the supply of aviation spirit, motive power for vast fleets of trucks, tanks, self-propelled guns, M.T.B's etc., and for the provision of lubricants for transport and industrial machinery. The demands have increased enormously in recent years and at the same time the discoveries of

crude oil reserves in the U.S.A., the greatest single supplier, have failed, since 1939, to keep pace with the increased consumption. In spite of all that has been done in other fields, natural oil remains the main source of liquid fuel and is rapidly becoming an important source of all power. In 1938, for example, 43·5 per cent. of energy used in the United States came from crude oil and its frequently accompanying natural gas.

Modern civilization is based on the exploitation of available minerals and not least among these is crude oil. Sources of petroleum, other than crude oil, are therefore essential. Natural gas at one extreme and coal at the other can now be converted to petroleum. Shale oil and tar sands can also be exploited to yield liquid fuels and the sum total of all the available sources is tremendous. These vast alternative supplies have not yet been tapped to any extent

A short time ago the problem of the industry was how to remove the available supply to its place of use. For this purpose tankers on the seas, tank-cars on the railways, vast fleets of trucks on the roads and last but not least the pipe-line, were all used. The 'Big Inch' line to supply the Eastern Seaboard in the U S.A. is the latest of these developments, but even Great Britain, smaller in area and with more limited demands, found the pipe line an essential method of transport in wartime. This new departure, a pipe line system of about 1,000 miles long, was constructed on a co-operative basis for the Petroleum Department by the Petroleum Board, the war-time organization of the petroleum industry in Great Britain, at a cost of some £7,000,000.[1]

The major problem now is the supply of the world's demands, including the supply of many raw materials, for chemical industries such as solvents, insecticides, alcohols, toluene, butadiene for synthetic rubber, etc. In 1938, more than 90 per cent. of liquid fuel in Great Britain was of petroleum oil, and almost all of it was imported. The total crude and petroleum products imported in that year was about 12 million tons, consisting of 2 million tons of crude and 10 million tons of finished or partly finished products. Including the freight this import was valued at £46,000,000.[2]

Petroleum, and indeed all liquid fuel, forms therefore a fit subject for community co-operative research Every citizen has a stake in the future of the petroleum industry. Besides providing fuel and lubricants, and raw materials for the chemical industry, it should provide also remunerative employment for a vast army. The preponderance of finished products imported over crude oil may be contrasted with the great export of raw coal. Research has a duty here to show how

[1]Since this was written the war-time secret of PLUTO—Pipe Line Under The Ocean—has been revealed.

[2]Co-operation between the Government and the oil companies in the search for oil in Great Britain has been rewarded by the tapping of a field in the East Midlands which has yielded about 400,000 tons of oil during the war, and by prospective fields elsewhere.

best to utilize our coal to the employment of labour and how to process crude oil for the products essential to the maintenance of an industrial civilization Apart from the Fuel Research Board co-operative research in the petroleum industry is not carried on in this country.

The last great source of power depends upon electrical industry which differs from the majority of British industries in being based upon scientific research. Reference has already been made to the simple commencement in the laboratory of Faraday, and it would be easy to dilate at length upon the benefits to the industry and, therefore, ultimately to the consumer, that have accrued from scientific research. Edison, to whom electricity opened great new fields of invention, thought that the practical limit of dynamo size would be 100 k.w. and expected the great stations of the future to be constructed with rows upon rows of 100 k w. machines. Later engineers put the limit at rather more than 10,000 k.w. but with the introduction of the steam turbine, modern turbogenerators of 75,000 k.w are not now unusual

By its incessant search for, and application of, new knowledge to extend the efficiency of its power production and distribution the industry has shown what research can do. The first electric arc lamp was set up in 1878 outside the Gaiety Theatre. Since then the progress in lighting has been stupendous. In 1880, the carbon filament lamp was the last word and used 4 watts of power per candle power. Successive stages of development through the tantalum filament, the tungsten filament, the gas-filled lamp with coiled filament led to the coiled coil lamp using only $\frac{1}{2}$ watt per candle power. It is estimated that by this economy alone the public has benefited to the extent of £3,000,000 a year. But even so the end was not in sight. Further research produced the sodium and mercury vapour lamps in which the efficiency was roughly trebled and shortly before the war the dream of the lighting engineer—'cold light'—was brought a stage nearer by the introduction of fluorescent powders with their additional advantage of daylight and better colours in place of the yellow or sickly green of the sodium or mercury vapour lamps.

From lighting, the uses of electricity have been extended in all directions. From that first arc light, has developed the electrified railway, the electric tramways, the motors that drive innumerable industrial machines, electric heating, welding and the electro-chemical industry. All this and much more was the outcome of research and it might well be asked whether anything remains to be done. But the industry was not satisfied with the independent researches carried on by the great undertakings. Fundamental problems, immediate needs common to the whole industry, were still crying out for solution. No adequately organized body for the investigation of these problems existed until steps were taken in 1917 to form an Electrical Research Committee. By 1920, an independent organization had come into existence under the title of the British Electrical and Allied Industries

Research Association, supported chiefly by the British Electrical and Allied Manufacturers' Association, the Institution of Electrical Engineers and the Cable Makers' Association, with Government assistance. To this, as time went on, were added the authorized electricity supply undertakings supplemented later by the Central Electricity Board.

In the early days, the work of the Association was carried on in the laboratories of supporting companies, the universities and the National Physical Laboratory The need for centralization became increasingly apparent, and in 1935 the E.R A. laboratories at Perivale, Middlesex, were opened. The value of these facilities has been such that the calls upon the resources of the Association can no longer be met within the limits of the Perivale site and the E R A. has joined with other research associations, similarly hampered, in the purchase of the Leatherhead site which is to form its permanent home after the war.

In common with the B.C U R A. the E.R.A. numbers among its supporters not only the manufacturers of electrical equipment, but also the electricity suppliers and the users of the equipment. It has grown rapidly and consistently and there is no evidence of saturation point being reached. Starting with an annual expenditure of £10,500 it now spends rather more than £100,000 a year and fully expects soon to reach £200,000 a year. As an indication of the value attached to research in the electrical industry it is estimated that the central research organization even now conducts only some 10 per cent. of the research in the industry, the remaining 90 per cent. being conducted in the laboratories of private firms. The electrical industry is, in fact, one of the most research minded industries in the country and in this the E.R.A. is fortunate, for it means that members of the association have on their staffs technical men who can appreciate and apply the results of the Association's fundamental work with the least possible delay.

For the future, the Institution of Electrical Engineers[1] suggests a co-ordinating body to vitalize and extend research which it is felt now suffers from lack of co-ordination The new body will not conduct research itself and will not necessarily be in any way dependent upon Government support. The British Electrical Research Board, as it is proposed to call the new body, will be the logical successor to the Universities, Engineering Institutions, National Physical Laboratory and the Department of Scientific and Industrial Research who have each taken the lead at different times and who have all suffered to some extent from lack of intimate contact with the industry. The object of the new Board will be the maximum progress in the application of research, for which it will need Government recognition though not necessarily Government control.

[1] *The Organization of Post-war Electrical Research*, May 1943 Report of the post-war Planning Committee appointed by the Council of the I E E in March 1941.

technical men in the industry are also held. Publication of matter of general scientific interest is encouraged and reports are published in the Journal of the Iron and Steel Institute

The Welding Research Council of much more recent origin, deals mainly with steel structures. It has no central laboratory and operates in the same manner as the Iron and Steel Research Council It is continuing work which has been carried on for some years under the ægis of the Department of Scientific and Industrial Research through various committees, in particular the Steel Structures Research Committee set up in 1931 and the Welding Panel.

The first autonomous research association in the industry was the British Iron Manufacturers' Research Association, founded by the British Puddlers in 1919 This Association received no grant from the Department and was wound up in 1925. The British Cast Iron Research Association, formed in 1921, is concerned with the melting, casting and moulding of iron, with the improvement of the properties of castings and with their examination and testing. The Association has nearly five hundred members and an income of about £25,000 a year.

Non-ferrous metals research is carried on chiefly by the British Non-Ferrous Metals Research Association established at the end of 1919. From a membership of 95 and an income of £7,000 in 1920 it had grown to 342 members and an income of £43,000 in 1942. The Association is supported at the present time by no less than nine trade associations, each representing a homogeneous group within the industry. Membership is open to all British industrial undertakings within the British Commonwealth who are producers, *i.e.*, engaged in mining and smelting, manufacturers, *i.e.*, producing cast or wrought products, or users, *i.e.*, fabricators of ultimate products such as machinery or structures, of non-ferrous metals. This extremely diversified body of members results from the nature of the raw materials which include aluminium, copper, lead, magnesium, nickel, tin, zinc and their many alloys

The Non-Ferrous Metals Research Association thus fulfils the function referred to in the previous chapter, of providing a central technical link between otherwise remotely related interests. As might be expected and as experience has demonstrated, the broad problems which the Association is called upon to solve are common to all the metals and the existence of the central laboratory enables it to synthesize the results of work on different metals into general principles Possibly because of the diversity of its interests the Association works on the project system more common in the United States than in Great Britain New projects are added to the programme of research as the need arises and to some extent this provides continuity of the field of investigation that is normally one of the main assets of a research association It is to the establishment of general principles that the Association devotes its interest after the objective of particular projects has been realized.

Some fifty major projects have been completed since its inception and about twenty such are maintained in constant operation.

Other co-operative research work in the field of non-ferrous metals has been, or is being, carried out by the Tin and Tungsten Research Board which arose out of *ad hoc* problems sponsored by the Department of Scientific and Industrial Research, and was wound up at the end of 1920; by the International Tin Research and Development Council; by the Copper Development Association; and by the Dental Investigation Committee of the Department which has sponsored work particularly on dental alloys and amalgams.

Much work related to the interests of the metallurgical industries is also carried out by other co-operative organizations such as the British Refractories Research Association and, since mid-1944, the British Coke Research Association. Previous to the formation of the latter Association, research work on hard coke had been carried out independently by the Midland, Northern and Scottish Coke Research Committees established in Sheffield, Newcastle and Glasgow respectively. The work of these committees was sponsored by the Iron and Steel Industrial Research Council and received financial assistance from the Department of Scientific and Industrial Research in the same way as the research associations.

Transport

Transport, like some of the other great industries, comprises a number of different types of undertaking each with its peculiar problems which when made the subjects of scientific research are often found to be fundamentally closely related. Transport covers the carrying of goods and passengers by road, rail, water and air. The immediate problems of road users are not the problems of carriers by sea, nor are those of the shipbuilders those of the aircraft constructors As might be expected in so heterogeneous an industry the application of research by co-operative means has followed a number of different patterns.

Of the first importance to the greatest number, perhaps, is research devoted to the improvement of road conditions. The present century has seen an unprecedented change in the structure of roads and the purpose for which they are used. The country lane of the early years of the century and the modern arterial highway hardly appear to be members of the same family. From a hardened pathway metalled to prevent slow moving horse traffic from sinking into it when wet, it has progressed to the concrete parkway designed to stand up to the stresses imposed by fast-moving loads of weights undreamt of by our ancestors.

The introduction of speed in transport has meant that, concurrent with the necessity for structural re-design, has come also the need for a re-design of layout. The roads have become a battle-ground on which the losses are too great for the country to face with equanimity. According to the National Safety Council of America, no less than 40,000 persons

were killed on the roads in the United States in 1941, and the total cost to the country of all road accidents was not less than $2,000 millions. In Great Britain, nearly 70,000 persons were killed and 2¼ million injured between 1930 and 1940 and it is estimated that road accidents are costing the country about £50 millions a year. It is evident that there is ample justification for the expenditure of large sums of money on research that will reduce this drain on the country's resources.

An examination of the statistics reveals that motor vehicles were involved in 85 per cent. of the road accidents but it is not easy to deduce the causes of accidents. That improvements to road surface, structure and layout are possible methods of reducing the accident rate is evidenced by the experiments conducted before the war jointly by the Ministry of Transport and the County Surveyor of Oxford[1] in which fifty-eight rural road junctions were re-designed with the result that in the succeeding twenty-one months there were no fatal accidents at these junctions, serious injuries were reduced by 79 per cent. and minor injuries by 37 per cent.

In the light of the accident rate, road research becomes a community responsibility and the first steps were taken by the Ministry of Transport whose experimental work, conducted on test roads and at the Road Research Laboratory at Harmondsworth, was financed out of the Road Fund. In 1932, responsibility for this work was transferred to the Department of Scientific and Industrial Research, although its cost was still charged to the Road Fund. In conformity with its usual practice in the carrying on of such community research schemes, the Department first set up a Road Research Board. In 1935, the title was changed to the Road (Materials and Construction) Research Board as indicating more clearly the functions of the Board, and particularly the limitation to considerations of engineering problems related to road construction and the materials used for it. The experimental work of the Board which is carried on at the Road Research Laboratory, the National Physical Laboratory, the Chemical Research Laboratory and the Building Research Station, covers subjects such as soil mechanics, surface irregularities, skidding, and materials such as concrete, bitumen and road tar.

An interesting feature of the research, which is duplicated in other similar research undertakings, is the extent of the further co-operation induced between the co-operative organization and other laboratories. The Board conducts work for the Road Tar Research Committee, for example, the Rubber Growers' Association and in conjunction with the Ballast, Sand and Allied Trades' Association.

Research into road transport problems is represented also in the true co-operative research field The Research Association of British Motor and Allied Manufacturers was formed in 1920 and the British

[1]Report by Select Committee of the House of Lords on Prevention of Road Accidents, 1938.

Motor Cycle and Cycle Car Research Association in 1921. The Research and Standardization Committee of the Institution of Automobile Engineers took over the work of these two associations in 1931 and 1932 respectively, thereby converting the type from co-operative to corporate research. The research income of the committee was about £24,500 in 1944 which with fees for services rendered, mainly to Government departments, made the total income rather more than £31,000. In addition to the work in its own laboratories on the outskirts of London the Committee conducts extra mural research in University laboratories, the National Physical Laboratory and member firms' laboratories.

It is noteworthy as showing the inter-play of related problems in research, that the British Coal Utilization Research Association carried out extensive and successful researches during the war on the conversion of liquid fuel internal combustion engines for road transport to the use of producer gas.

As an island nation, shipping and ship-building must of necessity occupy an important place. The influence of the shipping interests on the development of refrigeration has already been noted. A considerable amount of research has also been carried on by Lloyd's Register and the British Corporation Register, chiefly in connection with the compilation of standards and the failure of ship structures or engines.

The Admiralty has for many years conducted research on ship-building, the greater part of which has been confidential, and individual firms have not been backward in *ad hoc* investigations. There has, however, been little co-ordination in the past Work by the National Physical Laboratory in the Froude Tank on models, has provided much useful information and enabled correlations to be made between model testing and full scale records, but the first co-operative effort occurred in 1938 when the importance to shipbuilding of advances in welding technique induced the Shipbuilding Conference to accept a large share of responsibility for the formation and financing of the Welding Research Council.

The next step in co-operative research in shipbuilding was the consideration, in 1942, of a memorandum by Sir Charles Darwin. Plans had already been made by the industry for a research association but then execution had been delayed by the war By 1944, however, it was decided to embark upon the scheme for the formation of the British Shipbuilding Research Association The Research Association will be governed by the Shipbuilding Research Association responsible to the Shipbuilding Conference and the research work will be directed by the Shipbuilding Research Board. So has come to fruition a long-term policy designed to place and keep British shipbuilding in the van of design and render it competitively efficient in all its branches. Membership of the Association covers shipowners, ship-builders, ship repairers and marine engine builders as well as the Admiralty and the Department of Scientific and Industrial Research.

The latest development in co-operative research in shipping was the formation in May, 1944, of an association to conduct Marine Turbine Research. This is not, in fact, an entirely new departure, since the new organization will carry on the work of the late Sir Charles Parsons in the works of the Parsons Marine Steam Turbine Co., Ltd. The organization commemorates Sir Charles in its name, which is to be the Parsons and Marine Engineering Turbine Research and Development Association It will be independent of the Shipbuilding Research Association but will work in close harmony with it. It will cover both steam and gas turbines and almost all, if not all the turbine manufacturing firms are members

Research in the field of air transport has from the very early days of the aircraft industry been a subject of community research. The official organization commenced with a report by Lord Haldane, when Secretary of State for War in 1909, on the need for a committee to advise the Government on the research necessary to create an efficient aircraft industry. The Advisory Committee for Aeronautics was accordingly created and the National Physical Laboratory organized a new division of aeronautics whose work was supervised by the Committee. The membership of the Committee was equally divided between representatives of Service and other Government Departments and representatives of the industry and the universities.

The organization of aeronautical research is a model of the co-operation that can be obtained between science and industry. Much of the experimental work is carried out in the laboratories of individual firms who have their own testing equipment and the remainder at the National Physical Laboratory at Teddington and the Air Ministry laboratories at Farnborough. It is questionable whether the industry could have advanced to its present state of efficiency without the guidance of the Advisory Committee and the co-operative facilities provided under its supervision. So successful has this particular form of organization been that it is the model for similar bodies in the United States, Canada and Australia.

An entirely different arrangement from any described hitherto was adopted for the prosecution of research specifically concerned with the possibilities of the jet-propulsion of aircraft. Work which had commenced with Government approval was later carried on by private enterprise in the name of Power Jet Ltd. When it became apparent that the work could not be brought to a successful conclusion without financial assistance, the Government made a contract with the company for research and development work and from the Spring of 1938 its work was carried on substantially with Government funds. At a still later date the development of the gas turbine reached a stage of immediate national importance and the Government decided to set up a research centre of gas turbine technology. To achieve this end rapidly, it was decided to retake full possession of the premises originally provided by

the State, to form the nucleus of a national centre. The success attending this new form of community financing of research of national importance is too well known to need further emphasis.

In one co-operative research organization the inter-relation of land, sea and air transport has been specifically recognized. The work of the British Internal Combustion Engine Research Association founded in 1943, covers a field which includes stationary and portable engines of all sizes, marine engines up to 1500 h.p. and power units for railways —all operating on any liquid or gaseous fuel. The combined effects of the large pre-war export trade (more than two-thirds of the British production of internal combustion engines, other than those used in aircraft and road transport, were exported) and the wartime demand for great numbers of internal combustion engines for special purposes such as landing craft, m.t.b's and other special vessels, tanks, mobile workshops and power stations, have encouraged the idea of the co-ordination of research in this field. Almost every manufacturer of internal combustion engines is a member of the new Association which, by conducting research on a whole-industry basis, is expected to contribute materially to the ability of the industry to recapture and expand world markets.

Textiles

The textile industries are the largest manufacturing industries in Great Britain. According to the Report of the Fifth Census of Production they employed, in 1935, almost one million persons and produced goods to a total gross value of more than £300,000,000. The industries differ particularly in their raw materials (the processes used being dependent upon the raw material) which comprise cotton, wool, linen, silk, jute, and rayon and synthetic fibres. In addition there are ancillary industries such as the hosiery and lace industries using the products of one or other of the sections of the textile industries. The additional employment provided in the clothing and other making-up trades and in the transport and distributive industries makes the textile industries of prime importance to the economic well-being of the nation. They play their part too in the export trade. The cotton industry alone was, in spite of its decline during the inter-war years, our greatest exporting industry at the outbreak of war in 1939. In 1937 our cotton exports were valued at £69,000,000. More than one half of the cotton cloth produced was exported.

For many reasons, including their structure, the industries, vast as they are on a national scale, are largely composed of small units. Referring to the Fifth Census Report again, 75 per cent. of the cotton spinning establishments producing 50 per cent. of the total output of yarn employ less than 300 persons each. In cotton weaving the proportions are 90 per cent. of firms producing 60 per cent. of the total cloth In the woollen and worsted industry 93 per cent. of the firms

producing between them 66 per cent. of the total output employ less than 400 persons, while in textile finishing 94 per cent. of firms accounting for 75 per cent. of the trade employ less than 400 persons. These figures may be contrasted with those for the modern industries such as rayon, in which 11 per cent. of the firms in the industry account for 67 per cent. of the output and employ about 750 persons each, or the electrical industry in which 12 per cent. of the firms account for 76 per cent. of the trade and employ about 700 persons each.

The industries are, in general, organized with a horizontal structure, that is progressive steps in the handling of the fibres are specialized and in the hands of what amount to individual industries To take cotton again as an example, the raw material is imported and handled by cotton merchants and brokers who pass it on to spinners for conversion to yarn. The spinners sell the majority of their output to manufacturers who weave the yarn into cloth, though some goes to the lace, hosiery, sewing thread and other industries. The cloth is passed on, often through the merchant converters, to the finishing section of the industry for bleaching, dyeing, printing, raising and the hundred and one other processes concerned with converting the products of the looms to the finished article of commerce. The handling of the finished cloth is done by a merchanting section. All these sections of the industry are highly organized, with their own practices and conventions rooted in a long history, their own trade associations and trades unions and each, though dependent upon the others, deals competitively with them

Up to the first world war the textile industries were largely dependent upon the inventive genius of individuals and too high praise cannot be bestowed upon such men as Hargreaves, Cartwright, and Mercer in the cotton industry for the advances they made which placed the industry in the forefront of technical progress and made Great Britain for many years the world's chief supplier of cotton textiles Nevertheless, advances in recent times had been few and the textile industries during the first world war were essentially unchanged technically from what they had been one hundred years earlier.

By reason of their size, their peculiar organization, the number and sizes of their units, their ancient customs and their position relative to export trade the textile industries offer a great challenge to co-operative research. Unquestionably large opportunities are there to be taken if the equally unquestionably great difficulties can be surmounted. Not the least of the difficulties, and one that has not so far been mentioned, is the relative absence of a technical textile philosophy. Most industries are based upon science, or technologies that receive sufficiently adequate attention in the universities to ensure the necessary background knowledge to provide a succession of trained researchers without too much difficulty The textile industries are technically specialized and until recent years there has been little or no research into the fundamental sciences that govern their techniques. This is probably the result of the inherent

difficulties of the subject. Technical Colleges teach the mechanics of textile processing which have been developed over a long period, and research work in textiles was for long confined to *ad hoc* researches on particular problems. Essentially the study of the textile fibres is a statistical study of the application of the physical sciences to variable colloids based on high polymers.

The textile industries are therefore very dependent upon self help in their approach to research, yet the greatest single technical need of the industry at the time of the first world war was an infusion of a new and investigatory spirit. The industries themselves recognized this need and were not slow to avail themselves of the opportunities offered in the new Government proposals for industrial research. The Wool Industries' Research Association[1] was in fact the third research association to be formed, and commenced its grant-earning period in October, 1918, only four months after the first association had been founded. The British Cotton Industry Research Association commenced operations in July, 1919, the Linen Industry Research Association in October of the same year and the British Silk Research Association in January, 1921. Rayon research was added as a separate section to the Cotton Research Association in 1928.

All the main fibres were therefore covered by co-operative research associations within a very short period and all the associations have been successful although they have each passed through difficult times. In view of the peculiarities of the industries they serve this was to be expected and great praise is due to the industrialists who displayed and maintained their faith in the new organizations and to the wise leadership that brought them through their times of stress. The British Cotton Industry Research Association, the largest of the research associations may be used as an example of their progress.

The first steps towards the formation of a research association for the cotton industry were taken in 1916, when the Advisory Council was asked to appoint a Committee to examine a scheme for research. Offices were rented in Manchester and a detailed scheme worked out to embrace the producing sections of the industry, that is spinning, doubling, manufacturing, bleaching, dyeing, printing, finishing, thread, lace and hosiery manufacture, and conduct research from the cotton plant to the finished article. The three early textile research associations were forced to find laboratory accommodation of their own and each solved it in much the same way. The Wool Association secured a large house and grounds in Leeds, the Linen Association a house and twenty acres of ground outside Belfast and the Cotton Association a large house and fifteen acres on the outskirts of Manchester

In the last instance, the house was converted to administration purposes and the housing of a library, while new and up-to-date labora-

[1]Known originally as the British Research Association for the Woollen and Worsted Industries

tories were erected in the grounds. The laboratories have been added to at frequent intervals in the intervening years until they now cover some three acres of floor space and house investigators in fundamental science, technical processing, engineering and statistics. The greater part of the capital expenditure involved has been met from funds other than income and particularly from grants for the purpose made by the Trustees of the Cotton Trade War Memorial Fund. This has relieved the income from an insupportable drain and has enabled it to be directed wholly to the actual prosecution of research. A recent acquisition is an additional house and seven acres of land adjoining the original estate.

As a consistently successful research association, though not without its times of trial, the British Cotton Industry Research Association is worthy of some consideration, for its progress has been marked by a steady application of successive principles that are becoming increasingly recognized as the basic requirements for successful co-operative research. Four of these principles stand out. The first is its attachment to fundamental research. The lack of fundamental understanding of the raw materials and processes of the textile industries has already been commented upon. From its inception the Association has been pledged to purely scientific studies without expectation of immediate return and in every field of its research it has been forced to extend the boundaries of natural science which have been insufficient in extent for the needs of the laboratory's investigations. The attitude is best summed up by an extract from the programme of research drawn up by the founders.[1]

"There are two possible lines of advance, namely:

(1) To attack problems directly by methods based on past experience, without seeking to investigate the fundamental nature of the processes.

(2) To try to understand the chemical and physical changes produced during manufacture and so to establish, gradually, a broad roadway along which future advances may be made.

"Each method has its proper place, but whilst the second may be slower in producing results at the commencement, it will undoubtedly be more fruitful in the long run. The solid advances of science are based on this method of fundamental research, and it is chiefly by its aid that the research association proposes to seek the advance of the industry."

The early years of the Association's work were therefore devoted almost entirely to fundamental scientific studies, many of which were published in scientific journals

A high proportion of fundamental investigation has remained an essential part of the work of the laboratory, but with time came the recognition that in industrial research, fundamental science must be a basis for applied research In due course, therefore, the Shirley Institute

[1] Sixth Annual Report of the Advisory Council for Scientific and Industrial Research. 1920–21, p. 25 (Cmd 1491).

(as the laboratories were named) turned its attention to applied research. Processing rooms for spinning, weaving and finishing were added to the laboratories and technical research was embarked upon with the same enthusiasm as had been the purely scientific research and with the advantages provided by the years of patient fundamental investigation.

Shortly before the war a further step in the research programme was taken—namely the initiation of development work. In an old industry like the cotton industry it is not sufficient to carry out fundamental research, nor even to show how it may be applied to existing practices. It is necessary to develop new practices to the point of industrial exploitation and this, as often as not, implies the production of new machines. In 1938, therefore, the Shirley Institute built a large machine shop for the purpose of producing prototypes of new plant and this has proved so successful that the final step has now been taken of organizing it as a separate engineering section for the design and production, in collaboration with the laboratories, of any new machinery or plant needed for the full exploitation of research ideas developed to the stage of successful application.

The fourth great principle developed successfully by the Association is the idea of an intimate liaison with the industry. New ideas are likely to be impracticable unless tested by informed experience, and successful new processes are of little value unless the industry is made plainly and early aware of them Much effort has therefore been spent on bridging the gap between the scientist and the industry. Enquiries into members' problems have formed a substantial background to the Institute's research programme, serving at one and the same time to keep the scientists in the laboratory in touch with the daily difficulties of industry and to keep aware in the minds of the industrialists the existence in the industry of the central organization for the dissemination of new knowledge

Perhaps the greatest contribution to this bridging of the gap was the formation, in 1929, of the Liaison Department. This department is staffed by practical men drawn from the industry, already conversant with its conventional processes and further trained at the Institute in the research outlook. They pay routine visits to all members and also special visits upon request, carrying with them the latest information from the laboratories which they can interpret to the industrialists in the language of the mills and free from scientific jargon. A bi-monthly Bulletin in non-scientific language, numerous pamphlets and confidential memoirs keep the industry informed of the latest progress, while before the recent war, regular opportunities for organized visits by members kept alive the interest of the industry in its research association.

In research associations, as in other spheres of labour, there is no easy nor quick route to success The faith of the founders can only be justified by events and without justification the faith soon fades. It is unreasonable and, indeed hopeless, to expect quick results. Flash-

in-the-pan efforts are worse than useless in this movement but sustained effort, well-directed over a long period, brings its reward This has been the experience of the British Cotton Industry Research Association and it points a lesson for the whole movement. The steady growth to maturity of the Shirley Institute is reflected in its finances. Its total income has increased steadily from £13,000 at the outset to £30,000 in 1929 and £85,000 in 1939. In the latter year an Enabling Bill[1] was passed by Parliament and provision was made in it for the introduction of a statutory levy to finance research for the industry. Although much of the Bill had necessarily to be postponed during the war, the portion dealing with the levy was retained in the abbreviated Act and the cotton industry became the first to adopt the statutory levy as a method of financing research. The levy, which is administered by the Cotton Board, does not account for the whole of the Association's industrial income; together with the additional subscriptions and the government grant the income in 1945–6 is expected to exceed £200,000.

A further indication of the present maturity of the Association and the place it has won for itself in the industry is to be found in the increasing calls made upon it for assistance in the solution of industrial problems other than the strictly technical Many problems of industry, superficially economic or political, have a technical background by which they must stand or fall and there has been an increasing tendency in recent years to seek the advice of the Association on these backgrounds in industrial negotiations and its co-operation as an unbiased objective observer of the industrial scene. No more gratifying tribute is likely to come to any co-operative research association

Much has been written here about the Shirley Institute, but this does not mean that there are not other successful textile co-operative research organizations The Wool, Linen and Silk Associations have already been mentioned. In 1936, the Silk Association, which operated for a small industry on a limited scale, closed its doors as a separate organization and, joining with the Shirley Institute, became the Silk Section of that institution, thereby effecting considerable economies in its running and benefitting from the sum of experience in fibre technology already amassed there A move in the opposite direction is now on foot by the rayon industry. In 1928, a Rayon Section, separately financed, commenced operations at the Institute. In 1944, however, the industry, through the British Rayon Federation, formulated plans for the formation of a new and autonomous Rayon Research Association in keeping with its rapid development to a major industry and it seems likely that this scheme may become effective in the near future.

The hosiery and lace industries have not hitherto contributed to research associations but proposals have recently been made to the hosiery industry which, if adopted, will mean that this industry will also subscribe to the co-operative idea. It is not considered likely that it will

[1]The Cotton Industry (Reorganization) Bill, 1939.

establish a central laboratory but rather that it will contribute to the various existing associations. Co-operative research in the jute industry has also been raised recently. Proposals for jute research were first made in 1918 and seemed likely to become effective. They did not, however, materialize and in the interim co-operative research in the country for the jute industry has been confined to the London Committee of the Indian Central Jute Research Committee. As a result of much work on the part of the Dundee Chamber of Commerce the decision was taken in 1945 to form a research board with the object of co-ordinating research for the whole industry.

The various textile research associations have also been associated with other co-operative textile enterprises. The Linen and Wool organizations, for example, have been assisted by the Empire Marketing Board and each by organizations in its own field, the Empire Flax Growing Committee and the International Wool Secretariat for example. Similarly, the Cotton Research Association has had from its inception very close co-operation with the Empire Cotton Growing Corporation,[1] a non-profit organization devoted to research work for the improvement and extension of cotton growing within the Empire.

All the Associations have also been represented in the deliberations of the Fabrics Co-ordinating Research Committee. This Committee was set up in 1920 to bring together the work on textiles being done by the Services and to effect an economy by, wherever possible, allowing the research associations to carry out the experimental work. When, in 1929, the similar co-ordinating Boards for Chemistry, Engineering and Physics were dissolved the Technical Co-ordinating Committee on Textiles and Clothing was reconstituted as a Fabrics Research Committee to advise on scientific problems arising in the specification of textiles for the Services.

One textile research association not so far mentioned, is the British Launders' Research Association, which unlike the other Associations is related not to an industry dealing with a particular fibre but to one carrying out a particular set of processes on all fibres. The Association started in 1920 and has continued steadily since that date. At the outset it found itself faced by industrial processes to which scientific investigation had not been applied and in which the methods employed were therefore largely rule of thumb. Its field covers broadly the washing, starching, drying and finishing treatments given to textiles, mostly in the made-up state, and it has devoted attention successfully for many years to bringing these processes under proper control.

Other Industries

There are many other research associations besides those already described under the large grouped industries. Much research, for example, is carried on for the building industry which benefits from

[1]Formerly the Empire Cotton Growing Committee of the Board of Trade.

the work of the Research Association of British Paint, Colour and Varnish Manufacturers, founded in 1926, and the Forest Products Research Station as well as from the community research carried on directly by the D.S.I.R. at the Building Research Station. According to official estimates three quarters of a million houses are needed for each family to have its own and a further half million to reduce overcrowding. The proposals for education will necessitate thousands of new school buildings. Bomb damage to houses, shops, factories and public buildings has been tremendous. Even normal repairs and decorations, almost suspended for six years, will provide years of work. In all these fields the aim now is to provide the best material and the right processes for the purpose. Gone are the days of the traditional building industry when the site was the workshop and the builders were dependent upon naturally occurring or simply manufactured materials, such as brick, stone, timber, plaster and the like.

A problem the size of that now posed to the building industry is an obvious one for community research The happiness of the race depends among other things upon the provision of good housing conditions, and the æsthetic satisfaction of our towns as well as the more practical level of rates, depends upon good planning and the selection of the best methods and materials for our buildings. The Building Research Station has accomplished much useful work but seems to have suffered in much the same way as the various agricultural research stations, in that the results of research have not been adopted by the industry and turned to practical account. The present shortage of labour and the demand for buildings fulfilling certain conditions often disregarded in the past, seems likely to bring the work of the Station into its own. To assist the adoption of the new ideas an Inter-Departmental Committee on House Construction was set up in 1942 and the Ministry of Works and Buildings has recently appointed a number of Committees for Post-War Building Studies and for the Establishment of Codes of Practice that will be national in scope. Attempts to establish new ideas in building after the last war failed, but there are now good prospects that the ideas resulting from much research and experience will be adopted without serious difficulty.

Of particular interest is the co-operative research carried on by the so-called 'key-industries'. These are usually defined as those which, although themselves small and in the national economy relatively unimportant, are essential to other industries. In an old industrial country like Great Britain, almost every industry is dependent upon others but some stand out in this connection. Included in these are the manufacture of magnetos, jewellers' lathes, fine chemicals, dyestuffs, scientific instruments and optical and scientific glass ware. These industries are characterized first by their essentiality to other industries which may use relatively small amounts of their products but which may depend upon those small amounts for the maintenance of whole industries,

and second, by the very high expenditure upon research necessary to keep them efficient, compared with the value of their output.

These industries, necessary in peace, usually become of outstanding importance in war. This was observed by Bismarck who, during the Franco-Prussian War, found Germany too dependent upon supplies of optical instruments from London, then the centre of fine glass-technology. The assistance given by him to the firms of Abbé, Scholt and Zeiss put them in the forefront as world producers of optical instruments and incidentally laid the foundations for the German supremacy in research in many other fields dependent upon accurate instrumentation.

The same realization came to the British Government during the first world war and assistance was promptly given to the industry. Scientific glass-ware was made a subject of community research and in due course assistance was given to the Institute of Glass Technology at the University of Sheffield. The story was repeated in the present war. In 1939, the industry employed 18,000 persons and handled business valued at £7½ million of which £2 million worth went to the export trade. By the end of 1942 the industry had expanded to employ some 50,000 operatives with an output valued at £30 million. In the inter-war years the British Scientific Instrument Research Association, formed in 1918, had gone far to re-establish the reputation of the British industry for high quality modern instruments. It has been the accepted policy of the Department of Scientific and Industrial Research to treat key industries, in particular the scientific instrument industry, more generously than other research associations in order that the full benefits of research may be reaped not by the producing industry alone, but by all industries that are dependent upon instruments and by research workers throughout the country.

The importance attached to dyestuffs led to the formation of a company—the British Dyestuffs Corporation—during the last war for their manufacture. The company had a share capital of £3,000,000 against which the Government advanced £1,500,000 secured by debentures and in addition agreed to a grant for research of £100,000 over a period of ten years

Other industrial co-operative research organizations fitted into the framework of the Government scheme include the British Boot, Shoe and Allied Trades' Research Association, founded in 1919; the Research Association of British Rubber Manufacturers also established in 1919; the British Leather Manufacturers' Research Association, formed in 1920, the Printing and Allied Trades' Research Association, formed in 1930; the British Pottery Research Association formed in 1937; and the Scottish Seaweed Research Association which commenced operations in 1944. In addition the Paper Makers' Association of Great Britain and Ireland have adopted a scheme for the constitution of a research association for the paper and board industry; and the British Institute of Radio Engineers has recommended the establishment of a British

Radio Research Institute for the investigation of fundamental problems of common interest to the radio and electronics industry.

The principle of co-operative research with government assistance has become firmly established in Great Britain and increasing numbers of industries are taking advantage of the unique advantages offered by the scheme. Nevertheless there remains considerable scope for the further exploitation of this national tool. Industries which have not yet attempted the co-operative development of technical resources may find it desirable to do so, and industries in which the research association idea has already been accepted may find it desirable to extend their financial commitments and to call upon the associations for an increased effort to face and solve their problems. Only in this way can industry face its future with equanimity by assuring itself of the high order of technical guidance it requires.

V

CO-OPERATIVE RESEARCH IN THE EMPIRE

THE IMPORTANCE OF co-operative research for the British Empire rests upon the twin foundations of the potential wealth of the Empire countries and their sparse population, which is reflected both in the numbers of their scientists and in the limited inducements they can offer to first class research men. The last difficulty is of particular importance to Canada where the neighbouring territory of the United States offers a more completely industrialized area, with better opportunities for, and larger rewards to, scientific men and to whom, therefore, the Dominion loses a considerable proportion of its most promising young research workers.

In the past, the Dominions have also suffered from the fact that much of their industry has been based upon an extension of the activities of British or, in some cases, American companies whose research work has been conducted in the parent companies' laboratories and imported whole into the overseas branches. They have tended to live, therefore, by scientific blood transfusion rather than by the healthy increase of their own scientific blood streams. Indigenous talent has failed to find the encouragement it needed and the proportion of plant control and routine scientific work has been unduly high.

One of the most serious results of the trend of events has been the neglect of natural sources of wealth possessed by the majority of the Dominions and Colonies. The recent war has emphasized the potentialities of the Empire's resources. This is particularly the case with the

Dominions which have been perhaps better equipped to take advantage of the opportunities. India has been an important contributor to the munitions potential of the United Nations with heavy chemicals, propellents and textiles well to the fore. Australia, well known for its gold deposits was shown, after the Japanese successes had interfered with the supply of tungsten, to possess on King Island, Tasmania, one of the richest known sources of this metal Canada, according to the Report for 1944 of the Department of Munitions and Supply, has become the greatest base metal exporting country in the world. In their agricultural products, wheat, wool, cotton, jute, fruits and timbers as well as countless smaller, but not negligible, products they possess unbounded possibilities. But up to now the main problem has been, and is likely to be for some considerable time ahead, the supply of scientific manpower to develop to the best advantage the resources known to be present.

It is not to be supposed that the needs of the Empire for scientific research have been entirely neglected in the past. Co-operative research in Great Britain has, in many fields, been of inestimable value to Empire countries. The participation of Australia and New Zealand in, and the benefits reaped by them from, the work on food preservation carried out under the Food Investigation Board have already been mentioned. The Forest Products Laboratory of the Department of Scientific and Industrial Research has maintained for many years an active liaison with Empire countries for whom much work of great value has been conducted on Empire timbers. In the very early years of its existence, and while the British Cotton Industry Research Association was in process of formation, the Department financed special researches into the production and improvement of Sea Island Cotton in the West Indies. Mention has also been made of the Empire Cotton Growing Committee and the Flax Growing Committee of the Board of Trade. The former, reconstituted as the Empire Cotton Growing Corporation, has been continuously active, particularly in the less advanced Colonies in the spread and improvement of cotton strains.

The work of the Imperial Institute has also been of vital importance to Empire countries. The Institute was founded in 1887 and after reconstitution was transferred to the Government by Parliament in 1902.[1] Its management was entrusted to the Board of Trade, although by an arrangement made later the Secretary of State for the Colonies became responsible for its administration. The Institute was originally constituted to co-ordinate and distribute information bearing on Imperial trade and later began to undertake research related to industry. The justification for this was that the purpose of the Institute, namely the encouragement of the trade and industries of the Empire, could not be completely fulfilled without a sound knowledge of the characteristics of Empire products.

[1]Imperial Institute (Transfer) Act, 1902.

At the beginning of 1923 the withdrawal of overseas contributions placed the Institute in financial difficulties and necessitated a review of its functions and future. As a result, the Institute was amalgamated with the Imperial Mineral Resources Bureau and brought more closely into association with the Department of Scientific and Industrial Research. Its work on the natural resources of the Empire has continued unchanged.

Empire countries themselves have not been slow to appreciate the need for research and the limitations imposed by their peculiar circumstances that have been particularly conducive to the exploitation of co-operative ideas both on a community basis and on the basis of voluntary association. At about the same time as the co-operative research movement gained impetus in Great Britain, the Dominions commenced consideration of similar schemes The experiment in Great Britain was closely watched by them and in varying degrees plans were laid for emulating the example set. As might have been expected the Dominions, although becomingly increasingly industrialized especially as a result of the impetus given by the first world war, were inclined to pay particular attention to research directed to benefiting agriculture.

Through all the efforts of the early years, however, ran a dolorous refrain of insufficient financial resources, and report after report was received of projects cancelled or rendered static from this cause. A scheme for an Imperial training institute in India was abandoned in 1921 for lack of money as was, for the same reason, a plan for the establishment of a Central Chemical Research Institute For reasons of economy the National Research Council in Canada fought a losing battle for many years to obtain a National Research Institute. The Forest Products Laboratory in Australia was for a time in imminent danger of extinction owing to lack of funds, and the extremely limited funds placed at the disposal of the Commonwealth Institute of Science and Industry at first severely restricted its usefulness. The Annual Reports of the various Governments of the time are repeatedly concerned with the shortage of funds in terms that seem usually to indicate that the true importance of community co-operative research to the welfare of their territories had not then been appreciated That this situation has very largely been corrected will be evident from the following accounts of activities in various Empire countries.

Australia

Co-operative research in Australia owes its inception to Government action and dates from the establishment in 1916 of the Commonwealth Advisory Council of Science and Industry The size of the continent and its sparse population made the initiation of research schemes with industrial participation a matter of great difficulty By the end of 1917, however, great progress had been made in cataloguing the researches in progress and the research facilities of the country with a view to

establishing the problems in urgent need of solution. Broadly speaking, the main demand at that time was for investigations directed to furthering the agricultural development of the Commonwealth. A Commonwealth Institute of Science and Industry, designed to carry out research in many different fields, including agriculture, forestry, mining and metallurgy was established in 1920 In 1921, the Australian National Research Council was constituted and the first Government research station—the Scientific Test House at Sydney, N.S.W.—was opened.

In 1925, a Conference called by the Prime Minister made far-reaching suggestions for the organization of the Institute and recommended that its attention should be devoted particularly to the forest products of Australia, to the development of liquid fuels, the preservation of food by refrigeration and canning, and the diseases of plants and animals, together with other small investigations. The programme laid down was anticipated to require an annual expenditure of £100,000. Following upon this conference, steps were taken to reorganize the control of scientific research in the Commonwealth and in 1926 the Science and Industry Research Act was passed which established as the controlling body, the Commonwealth Council for Scientific and Industrial Research with Committees appointed by the States as its advisers. The aims of the council, which included the conduct of research on a national basis, the training of research workers, and the assistance of associations for the purpose of research, were similar to those of the Department of Scientific and Industrial Research in Great Britain. A sum of £250,000 was appropriated under the Act and made into a Trust Fund for financing experimental work carried out by the Council. A further Trust Fund of £100,000 was to be applied to the training of research workers.

The Council, which has continued as the co-ordinating organization of Australian research, proceeded to organize its more important work into divisions By 1943, its annual expenditure had exceeded £500,000, of which rather more than £400,000 came from the Treasury. The divisions then in operation included the Division of Plant Industry,[1] the Division of Soils,[2] the Division of Forest Products, the Division of Food Production, Division of Fisheries Investigations and Division of Industrial Chemistry. Aeronautical research, organized on the lines of the Advisory Committee for Aeronautics in London, was established in 1937 with a laboratory under the control of the Council.

The main work of the Council has continued from the first to be chiefly concerned with the primary industries and it has been a stated policy that research for the secondary industries should, in general, be carried out by the industries themselves. It has always been expected

[1]Comprising the Animal Health Research Laboratory, Melbourne, Mc.Master Animal Health Research Laboratory, Animal Nutrition Laboratory, Adelaide

[2]With laboratories at the Commonwealth Research Station, Marbeen, Victoria, and the Irrigation Research Station, Griffith, N.S.W.

that in due course, research associations on the model of those in Great Britain would be established in Australia but little progress had been made in this direction until 1944, when it was announced that co-operative research on a lavish scale was to be provided for the wool industry. The Australian Wool Board, which has been reconstituted for the purpose, anticipates an annual expenditure of £600,000 raised by a tax on wool of 2/- per bale together with an equal contribution from the Treasury. With this money, research will be conducted on problems of primary production, of the wool textile industry, and of general national and international economics of the wool industry.

New Zealand

In 1916, the New Zealand Government took the first steps towards the co-ordination and extension of research for industry. The British and Dominion schemes were considered in detail, but it was not until 1919 that an Industries Committee of the House of Representatives made definite recommendations for the establishment of a central 'Board of Science and Industry' with an assured income. At about the same time a bequest of £240,000 was made by Thomas Cawthron for the establishment of a research institute. The Cawthron Institute, established at Nelson, in 1920, was the first concrete step in the organization of research on a national or co-operative basis Its work, as might be expected from the character of the country, has been directed particularly to the solution of problems in agriculture and fruit growing. No further steps were taken until, in 1924, a conference of New Zealand manufacturers submitted proposals for a Treasury-assisted Bureau for the encouragement of research directed towards the utilization of the country's resources and towards the assistance of groups of manufacturers. In 1926, the Department of Scientific and Industrial Research was established under an Act of the House of Representatives.[1]

The Department so constituted resembled in its functions its counterpart in London. It became responsible for the administration of Dominion Scientific services such as the Geological Survey, the Hector Observatory and a new State Laboratory for Standards and Tests which was to incorporate the existing Dominion Laboratory. A proposal was made in the same year for a dairy research institute. Co-operation with industry has been a key-note in the Department's policy since its inception After completing a survey of the researches in progress it was proposed to inaugurate work on some of the outstanding problems, not simply as State projects but in association with the industries concerned.

In fulfilment of this policy, wheat growers, flour millers, bakers and the Department co-operated in the establishment of a Wheat Research Institute at Christchurch, the majority of tanners in the Dominion assured

[1]Scientific and Industrial Research Act, 1926. an Act to make Provision for the Promotion and Organization of Scientific Research and for its Application to the Primary and Secondary Industries of New Zealand.

by their support the formation of a Tanners' Research Association, the Department and the coal owners co-operated in the formation of a Fuel Research Association; the meat processing industry co-operated for the carrying out of research into the general problems of the industry; and the flax growers and manufacturers also formed a co-operative research association. The last named association was put on a sound financial basis by the introduction in 1929 of levies of 2d. per bale on hemp, 1d. per bale on tow exported and 1s. per acre on all established flax-growing areas.

Co-operation on an Imperial scale was also envisaged and the Empire Marketing Board gave its assistance to several research projects of wider than local importance With considerable vision the Department for long refrained from co-operative schemes for the wool and cold storage industries pending the exploration of the possibilities of organizing co-ordinated schemes for the Empire. Within the limitations to be expected from the scale of the Dominion's resources, New Zealand appears to have appreciated and acted upon the spirit of co-operative research more nearly than any other section of the Empire.

Canada

Canada is perhaps the most industrialized of the Dominions though, like others, it is largely a country of primary industries. It possesses an immense potential wealth of forest, prairie and ocean. In more than 50 per cent. of its territory the wild life is the mainstay of the population. It possesses in addition vast mineral reserves; it is the greatest single producer of nickel and during the war was responsible for 95 per cent. of the combined United Nations' output. Copper, lead, zinc, aluminium, mercury, magnesium, tungsten, mica and asbestos are all available in quantity sufficient to form the basis of industry. The expansion of aluminium production during the war has culminated in the construction of a hydro-electric plant in Quebec Province comparable with the Boulder Dam scheme in the United States.

With this vast potential available for tapping, it might be expected that industrial research would be a flourishing industry in Canada. Singularly enough its pre-war expenditure on research was small and confined for the most part to University and government laboratories In 1942, nearly 90 per cent of the research workers were in institutions of the latter sort, while of the professionally qualified scientists in industry more than 70 per cent were engaged chiefly on plant control [1] This is not because Canada is apathetic towards research Indeed the Dominion had early received a never-to-be forgotten lesson when research saved farming from its threatened extinction by the rust disease of wheat. The main reasons for the very limited research expenditure were undoubtedly the small population, with its correspondingly small

[1] *Survey of Scientific and Industrial Laboratories in Canada*, Dominion Bureau of Statistics.

scientific proportion, and the number of American and United Kingdom concerns operating in the Dominion but conducting their research elsewhere The small available scientific resources and the large prizes to be won by research make Canada an almost ideal ground for the growth of co-operative research. The rapid industrial advances and the needs of the war years have, in fact, resulted in research expenditure having increased about five-fold almost entirely by Government action and at direct Government expense.

Nevertheless, co-operative research in Canada, as in other parts of the Empire, has been a plant of slow growth. As early as 1916, an Order in Council was issued establishing an organization for the promotion of industrial research similar to that in Great Britain and the Research Council Act of the following year set up the Honorary Advisory Council for Scientific and Industrial Research. At this early date it had already been recommended that a central testing station and an associated central research laboratory for the use of trade research 'Guilds' should be established.

Detailed plans for the National Research Institute were elaborated in the following year, but a Bill introduced in 1920 to this end was defeated in the Senate on grounds of economy It was not until 1929 that the building of laboratories in Ottawa was undertaken. In the meantime the Honorary Advisory Council, which had been reconstituted as the National Research Council in 1924, had been forced to concentrate its activities along three main lines—the training of research workers through the provision of financial aid, the assistance of investigators of special problems by grants, and the organization of Canadian research into Standing Associate Committees of the Research Council.

The policy of working through Associated Committees has continued to be a characteristic of Canadian co-operative research. These committees are appointed on the initiation of any major field of work. They survey the ground, determine the kind, extent and location of the research and finally direct any research activities that may be undertaken In 1943, there were forty such committees and more than one hundred sub-committees covering many aspects of scientific research of importance to the Dominion and including the Corrosion Research Committee, the Field Crop Hazards Committee, the Gas Research Committee, the Weed Research Committee, the Magnesium Products Committee and the High Voltage Committee. The new Aeronautical laboratories on the outskirts of Ottawa are the responsibility of the Committee on Aeronautics.

The establishment of the National Research Council Laboratories enabled the Council to be less dependent on the voluntary collaboration of research workers and to conduct research on important problems at its own expense. The original temporary laboratories were replaced by the present excellent building in 1932. In the main the Laboratories fall into a class about half way between the Bureau of Standards in Washington and the National Physical Laboratory in London. The

Laboratories are organized into five main divisions—Applied Biology, Chemistry, Mechanical Engineering, Physics and Electrical Engineering, and Plans and Publications. The last-named Division is responsible for the publication of the Canadian Journal of Research now issued in six sections under a joint editorial board of the National Research Council and the Royal Society of Canada.

The proximity of Canada to the United States has had, as might be expected, an influence on the organization of its research work. Trade research associations on the style of those in Great Britain have not developed, but co-operation for the carrying on of research projects on the fellowship plan as practised in America is common. The National Research Council laboratories, in addition to its own research, conducts sponsored research projects for interested industrial groups. Such a scheme is operated, for example, by the Canadian Research Institute of Launderers and Cleaners. The latest development of the work of the Council and the further influence of American proximity is reflected in the decision to erect a PrairieRegional Laboratory in Saskatoon which will concern itself with research into the utilization of agricultural crops.

A similar venture to the Ottawa laboratories has been undertaken in Toronto where the Ontario Research Foundation was established in 1928 under an Act of the Provincial Government. The greater part of the Foundation's work consists of sponsored projects in the industrial field. In its sixteen years' existence, the Foundation has carried out investigations for several hundred Canadian firms and once again emphasized the success that can attend the Research Foundation organization in congenial circumstances. Like most other Foundation laboratories, the Ontario Research Foundation also conducts independent research, in advance of industrial demand, in fields of exceptional promise. Other Provincial Governments, for example Alberta, Saskatchewan and British Columbia have also organized Research Councils under Acts passed by the local governments, but they do not appear to have developed them to the point of instituting directly controlled laboratories.

South Africa

In common with the other Dominions and Great Britain, South Africa early recognized the new spirit in industrial research. In 1916, an Industries' Advisory Board was appointed, the members of which were drawn from the business interests of the Dominion. Very early in its deliberations the Board appointed a Scientific and Technical Advisory Committee to deal with, among other things, provision for, and co-ordination of, industrial research and co-operation with similar organizations elsewhere. Both the Board and the Committee were made responsible to the Department of Mines and Industries. In 1917 the Board and the Committee were amalgamated under the title of the Advisory Board of Industry and Science.

The essentially business and commercial outlook of the Board was reflected in its work. It was dissolved in 1923 after six years' work, during which time the Industries Division of the Department of Mines and Industries was placed on a firm basis; an official Journal of Industries, dealing with trade and commercial developments and industrial growth, was established; a Board of Trade and Industries was set up to deal with tariff matters; a Research Grant Board was instituted to handle applications for grants for research and related matters; and surveys of the fisheries, minerals and flora of the Dominion were commenced. A proposal for the formation of a Ceramics laboratory was still-born.

Since 1923, the co-operative research work of the Dominion has been almost entirely of the community type, carried out by different Government Departments, including the Departments of Agriculture, Forests and Mines and Industries. The first of these carries on research on experimental farms, at the National Herbarium, in the laboratories of the Chemical Division situated at Pretoria, Grootfontein, Johannesburg and Cape Town. The Forest Department conducts research at the Deepwalls Research Station and at the Wood Preservative Station at Pretoria. The Department of Mines, in addition to the geological survey, conducts research into safety in mines.

The attempts to co-ordinate research for industry in South Africa has been a story full of vicissitudes. In 1923, the work of the Board was assumed by the Industries Division of the Mines and Industries Department. The South African Journal of Industries ceased publication at the end of 1925 and at the beginning of the year the work of co-ordination was once more transferred, this time to the Board of Trade and Industries. Its work was mainly of an economic investigatory nature rather than of experimental or scientific research. Based on a report by a Coal Research and Survey Committee appointed in 1927, a Bill was drafted in 1928 for the establishment of a Fuel Research Institute and a Fuel Research Board on the lines of the corresponding organization in Great Britain. The Act was passed in 1930. On the whole the union does not appear to have proved a congenial soil for the growth of co-operative industrial research.[1]

India

In no country in the Empire is the need for co-operative research greater than in India. Its potential wealth, the need to raise the standard of living of its inhabitants and the recent rapid development of its industries combine to make research of the first importance, while the dearth of scientists proportionate to the size and needs of the country, and the small units which make up many of its industries, combine to emphasize that the research must be conducted on a co-operative basis if it is to be effective. At the present time there is every indication that

[1] A new Council for Scientific and Industrial Research has recently been constituted and held its first meeting in the summer of 1945. The Council will conduct research, organize it in all its forms, create new laboratories and encourage universities.

a strong co-operative system will be built up, but it is of comparatively recent origin.

In 1920, when co-operative research had become established in Great Britain and was being actively pursued in the Dominions, the Report of the Chemical Services Committee found that India was not yet in a position to adopt the plan of industrial research associations and that a more intimate system of State assistance was necessary It recommended that a Central Research Institute should be established at Dehra Dun and that Provincial Research Institutes should be set up in each Province Financial stringency forced the postponement of the Central Research Institute scheme and the abandonment of a proposal to establish an Imperial Tanning Institute, but India's steps towards the production of an indigenous co-operative research scheme, though somewhat halting, made surer progress than in the other overseas territories of the Empire.

Three main and distinct lines of advance may be discussed, namely, central co-ordination schemes, State and Provincial schemes, and Commodity Committee schemes Community research of the type carried on in all large countries is also done in India The Department of Agriculture, the Posts and Telegraph Department, the Botanical and Geological Surveys, and the Indian Ordnance all carry out research work of importance to their own interests. The Imperial Council of Agricultural Research has recently decided to open an Indian Institute of Fruit Technology at Lyallpur and there is also a flourishing Forest Research Institute at Dehra Dun, in the United Provinces. The Indian Institute of Science at Bangalore, established largely by generous gifts from the Tata organization, devotes considerable attention to the scientific investigation of problems of economic importance to India.

States and Provinces also contribute to the support of community research. There are many excellent centres of agricultural research, though in relation to the size of the country and the importance that must be attached to its agriculture they are still too few and too small. The States and Provinces also have for the most part Departments of Industries and Commerce which both conduct and finance research projects of domestic importance. A Technological Institute at Cawnpore and a Woodworking Institute at Bareilly are run by the United Provinces' Government. Bengal has a Tanning Institute run under the auspices of the Department of Industries and Madras has a Leather Trades' Institute similarly controlled A Scientific and Industrial Research Board has been set up by the Government of Hyderabad

It has been stated that India was unready, in 1920, for the adoption of the research association scheme and, in fact, the scheme has never yet borne fruit in India. Nevertheless, there are research associations which bear the imprint of a true natural growth fitted to the country, devoted to important agricultural products, and characterized by their method of financing The first of these was the Lac Research Association

which was created and provided with funds raised under the Lac Cess Act in 1921 by a cess on exports. The Association has a Research Institute at Ranchi, maintains a London Office known as the London Shellac Research Bureau, and is comprised of European and Indian shippers, manufacturers and brokers. It is therefore a co-operative enterprise in the widest sense.

The most characteristic of Indian forms of co-operative research is the scheme of Commodity Committees. These have been founded on the general principle that the trade concerned should provide funds through the levy of a cess at some stage in the production—usually on the raw material. The Committees do not supplant but supplement State or Provincial Government organizations and they are concerned entirely with the promotion of research—agricultural, technological and economic—for the improvement of the commodity and its utilization. They also serve as centres of information and aim by their investigations and the distribution of information to improve the marketing of their products.

The first of these Commodity Committees was the Indian Central Cotton Committee which, by the Cotton Cess Act of 1923, provided for a duty of 4 annas on every bale of Indian cotton produced, whether used at home or exported. Out of the funds provided the Committee established a technological laboratory in Bombay in 1925 at an initial cost of £40,000, and an agricultural and plant breeding centre has been set up at the Institute of Plant Industry at Indore. Proposals were also made in 1921 for the formation of a Sugar Research Institute but financial stress prevented this proposal being carried through until much later. The Indian Central Sugar Cane Committee now operates the Imperial Institute of Sugar Technology at Cawnpore. The Indian Central Jute Committee operates a central Technological Research Laboratory financed out of an allocation from the export duty. Before the war India produced one quarter of the world's oil seeds and this important commodity is represented by the Indian Central Oil Seeds Committee. The Indian Central Coconut Committee has recently been constituted for the improvement and development of the coconut industry, which is the mainstay of economic life in Travancore, Cochin and Malabar. An Indian Central Tobacco Committee has also been agreed upon but is not yet in operation.

Centralized co-ordination of research is of very recent growth in India. An Industrial Research Bureau was established in 1934 but the real impetus came with the outbreak of war in 1939 when India found herself in much the same position as Great Britain in 1914. The supply of many vital products was curtailed and the necessity for co-ordinated research was immediately recognized. A Board of Scientific and Industrial Research was set up in 1940 for a period of two years. Its functions were to advise the Government on matters relating to scientific research, to conduct research in its own organizations, to

utilize and co-ordinate existing research organizations, and to recommend the lines upon which industrial research should be pursued. The Board operated through research committees, nineteen of which were established during its two years' existence.

When certain of the earlier researches had reached the stage of commercial exploitation, an Industrial Research Utilization Committee was formed to agree the terms upon which the results could be released to manufacturers for exploitation. In 1942, the functions of the Board and the Committee were placed under the Administrative Central Council of Scientific and Industrial Research. The Council has been established on a permanent basis and is financed by the Industrial Research Fund. Up to the present the Council has been concerned mainly with immediate problems of wartime urgency, though some attention has also been given to the organization of research to benefit Indian industry. One important aspect of its work has been the development of useful products from Indian raw materials. A number of completed processes have already been leased to industry and negotiations for the lease of others are being conducted by the Industrial Research Utilization Committee.

A central Chemical Research Institute has been established at Delhi and plans have been prepared for the formation of National Physical Laboratories and a Metallurgical Research Institute. A Central Glass and Silicate Research Institute has been decided upon. It is to be located at Calcutta and the United Provinces Glass Manufacturers' Association and the Bengal Glass Manufacturers' Association have each subscribed Rs. 10,000 towards the cost of the Institute. The scheme thus becomes a corporate co-operative research project. Arrangements have also been made for a Central Fuel Research Station on a site of 100 acres donated by the Rajah of Jharia. All these activities will be under the jurisdiction of the Council of Scientific and Industrial Research which, to give publicity to Indian research activities, particularly those organized under its direction, now publishes a quarterly Journal of Scientific and Industrial Research.

The Council of Scientific and Industrial Research appointed an Industrial Research Planning Committee in 1944 to make an exhaustive survey of existing research facilities in India and to recommend measures for the development, co-ordination and planning of future research activities. The report of the Committee, recently published, stresses the present inadequacy of Indian industrial research and recommends the formation under Government auspices of a National Research Council composed of representatives of science, universities, industries, labour and administration.

The functions of the Council will be similar to those of the Department of Scientific and Industrial Research and its executive arm will be a small body to be known as the Research Board. This Board will be in charge of all the laboratories and institutes set up by the Council, will

assist in the setting up of research institutes by industries and will prepare comprehensive plans of desirable research programmes. The establishment of National Chemical and Physical Laboratories is envisaged as well as the formation of nine specialized institutes engaged in researches on food technology, metallurgy, fuel, glass and silicates, oils and paints, buildings and roads, leather and tanning, industrial fermentation, and electro chemistry. A National Trust for Patents and a Board of Standards are also recommended in the Report

The rapidly developing pattern of co-operative research in India gives promise of great strides in the near future and points an important moral that the wholesale transplantation of methods is unnecessary and unwise. To be successful, the movement and its organization must be indigenous It is a plant that cannot be forced either in time, or habitat, or growth. The research associations of Great Britain, the research foundations of the United States and the Commodity Committees of India are the natural results of the needs, temperaments and conditions of their environments.

The Colonies

The Colonies are predominantly agricultural and this has militated against the development of large scale research since their financial resources have been incapable of supporting what has often been mistakenly considered a luxury available only to the wealthy, rather than a necessity of particular value to the poor Much of the research work for the Colonies has therefore been financed from without. The work of the Imperial Institute in conducting chemical investigations on Empire raw materials and of laboratories such as the Forest Products Research Laboratory have been referred to earlier. Unofficial and commercial undertakings working on a co-operative basis have also contributed greatly to the expansion of industrial research in the colonies.

The Empire Cotton Growing Corporation, already mentioned, has research stations in the West Indies, East and West Africa and is planning another in Uganda. There are also a number of research institutes scattered about the Empire, which are financed by means of a cess levied on the participating industry. The Rubber Research Institute in Malaya, the Tea, Rubber and Coconut Research Institutes in Ceylon, the Sugar Experimental Station in Mauritius, the cotton experiment station in Kenya and the Sisal Experiment Station in Tanganyika are examples of this method of organizing research in the Colonies These efforts are unfortunately limited in scope—the largest being the Rubber Research Institute, Malaya, with a staff of twenty-five.

Research projects in the Colonies have also been financed by various foundations and trusts including the Leverhulme and Rhodes Trusts, the Rockefeller Foundation and the Carnegie Corporation. The Empire Marketing Board, has also financed investigations on colonial products. In addition, fundamental research is undertaken by such institutions

as the Imperial College of Tropical Agriculture in Trinidad, B.W.I. and the East African Research Station at Amani, Tanganyika.

Colonial Governments have also shown their willingness to support research within the limitations of their funds. Cacao research in Trinidad is financed jointly by the Governments of Trinidad, Nigeria, Gold Coast and Grenada; the West Indian Sugar Cane Breeding Station is supported by Barbados, Jamaica, Trinidad and the Leeward Islands. Further, a great deal of research has been carried out under Colonial Government auspices by the technical services. These services—medicine, education, agriculture, animal health, forestry etc.—have developed greatly in recent years and many of them have specialists attached to them who devote some part at least of their time to research, though much of it is often taken up by routine work.

It cannot be considered that scientific research in the Colonies, which in the nature of the case must be co-operative in type, has been adequate in the past nor has sufficient responsibility in this direction been accepted by the Colonial Office. This is not that it has not been appreciated that considerable responsibility rested with the United Kingdom Government, but every early attempt at the organization of the development of Colonial raw materials was frustrated At the end of the last war, Parliament voted £100,000 to be expended over five years on furthering research in the Colonies but after two grants of £10,000 the funds were reduced to £2,000 a year.

The Research Committee set up to administer the fund came to an end in 1928 and a new Colonial Development Act was passed in 1929. Under the new Act up to £1,000,000 a year could be spent on development, a term in which research was comprehended. During the eleven years for which the Act ran, rather less than £600,000 was spent on research for the Colonies. The Empire Marketing Board, to which reference has several times been made, was dissolved in 1932 but a special Colonial Empire Marketing Board was set up in 1937 and financed investigations into a number of colonial products The activities of the new Board were suspended in 1939, on the outbreak of war.

In 1940, a fresh impetus was given to the whole question of research on behalf of the Colonies by the passage of the Colonial Development and Welfare Act. Under this Act special arrangements were made to finance research separately from welfare and development. Provision was made for the expenditure of sums up to £500,000 a year on Colonial research in addition to the provision of up to £5,000,000 a year for welfare and development A Colonial Research Committee was appointed in 1942 for the double purpose of advising on the expenditure of the monies provided for research and of co-ordinating the whole range of colonial research irrespective of the method of financing. The first Report[1] of the Committee was published in 1943.

[1]Colonial Research Committee. Progress Report, 1943, H M.S O. Cmd 6486.

Before the Committee was appointed it had been decided to set up an organization to conduct research into the utilization of colonial products. The Colonial Products Research Council was therefore appointed in 1943, not in an advisory capacity but as an executive body with its own Director of Research It is independent of, but will work in close association with, the Colonial Research Committee. Its terms of reference include a review of Colonial production; advice on the likely value of Colonial raw materials for manufacturing purposes; the initiation and supervision of research on raw materials; assurance that full use is made of existing research organizations such as the Department of Scientific and Industrial Research and the Agricultural Research Council. By the last provision arrangement is made that the whole system of Government-aided co-operative research is drawn into a coherent and close-knit framework.

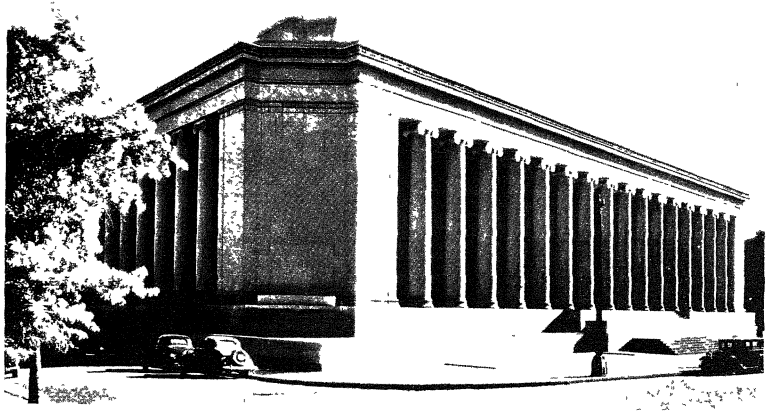
The approach of the Council to its problems has been modelled on that of the existing organizations No attempt has yet been made to concentrate research into a single institution, but support has been given to research projects carried out with existing facilities. The immediate programme of the Council has been to initiate investigations into commodities upon which large numbers of people depend for their livelihood and which are least well served by existing research organizations. Research on rubber, textiles, tea and timber, all of which are already catered for albeit on a too limited scale, have accordingly been deferred while attention has been concentrated upon sugar, vegetable oils, essential oils and vegetable drugs

The Director of Research is accommodated at the Imperial Institute but the functions of the two organizations supplement each other rather than overlap. A further step in the organization of Colonial research has recently been undertaken with the passage of the Colonial Development and Welfare Act of 1945. In particular the new Bill provides for the extension of funds and of the period of their availability. Under the 1940 Act, £5,000,000 a year was to be made available for welfare and development up to 1951 and £500,000 a year for research without a time limit. The new Act retains the feature of no time limit for the availability of the research funds but provides £120,000,000 for all purposes between 1946 and 1956 of which up to £1,000,000 can be spent on research schemes in any one year and up to £17,500,000 for all purposes in any one year.

The wise expenditure of the sums now provided, which are more in line with the needs of the colonies if the full benefit of research is to be realized, should go far to raise the standards of these territories and enable them to make a full contribution to world prosperity.

THE SHIRLEY INSTITUTE, MANCHESTER

Headquarters of the British Cotton Industry Research Association



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VI

CO-OPERATIVE RESEARCH IN THE UNITED STATES

CO-OPERATIVE INDUSTRIAL RESEARCH appears to have originated in the United States in the late 1880's when the cane sugar producers of Louisiana found themselves threatened by the competition of the beet sugar producers. The latter were using scientists to improve their yields of sugar and their methods of extraction. The cane sugar producers decided to meet the challenge by the same methods and established a Sugar Experiment Station first at Kenner and later at Audubon on the outskirts of New Orleans. The shortage of trained men to staff the experiment station led to the foundation of the Audubon Sugar School in 1891 which was run in conjunction with the experiment station. The funds for these organizations were contributed entirely by the sugar cane planters of Louisiana.

This initial experiment in co-operative research, starting so soon after the beginning of organized industrial research in America did not, however, have very great repercussions. As in Great Britain, it was not until the advent of the first world war with its threatened shortage of vital dyes, drugs, glass, etc., from German sources, that the Americans awoke to the necessity for intensive scientific research. The experiences of that time, during which the Chemical Foundation was organized and the National Research Council formed, proved the value of co-operative research. The remarkable growth of American industrial research from the period immediately following the war, necessitated serious consideration of improved methods for co-ordination of, and co-operation in, research activities. Industrial research in the United States has expanded in the last 25 years to almost ten times its original size and now employs some 70,000 scientists in all kinds of industries. It is not surprising therefore that the United States has experimented with many different forms of co-operative research for industry.

In spite of this adventurous outlook, co-operative research in America constitutes a very small proportion of the total research effort. Of 2,264 companies listed in *Industrial Research Laboratories of the United States*,[1] only 286 (*i e* 12·6 per cent.) reported that they were supporting co-operative research by fellowships, grants or through trade associations. It is striking too, that apart from genuine community research carried out by Government Departments, there is no Government assistance of co-operative research comparable with that afforded through the Depart-

[1] *Industrial Research Laboratories of the United States* 7th Edition National Research Council, 1940.

ment of Scientific and Industrial Research in Great Britain.[1] The freedom of action thus engendered has given rise to a variety of co-operative research organizations among which the following main types may be distinguished.

Government Laboratories.
Research by Trade Associations.
Independent Fellowship Laboratories.
Regional Research Laboratories.
University Research Foundations.

Government Laboratories

Community co-operative research in the United States is carried on by the Government in much the same fields as elsewhere, *i.e.*, chiefly in fields where the public interest is largely involved and the immediate incentive to competitive industry is small. The main exponents of scientific or technical research, discounting the Services which as in other countries conduct specialized research for their own purposes, are the Department of Agriculture, the Department of the Interior, the Department of Commerce, and the Federal Security Agency which operates the Public Health Service To these may be added also the Advisory Committee for Aeronautics In general the research activities of these Departments is carried on through bureaux established for the purpose. Thus, the Department of the Interior, which is responsible for the conservation and utilization of the mineral resources of the country, operates the Bureau of Mines as well as the Geological Survey and the Fish and Wild Life Service; the Department of Commerce operates the National Bureau of Standards. This establishment, which conducts research relating to standards and properties of materials, and develops instruments of precise measurement, is unique in that it operates a research associate plan used by many industries and trade associations for the prosecution of co-operative research. In recent times there have been upwards of fifty research associates representing about fourteen different industries stationed at the Bureau. In particular, industries that are interested in work involving the accurate determination of small variations find it advantageous to take advantage of the Bureau's experience in this field by stationing a research worker in the laboratories there.

[1]Since this was written the report of Dr Vannevar Bush, Director of the wartime Office of Scientific Research and Development, to the President of the U S A has been published under the title *Science: the Endless Frontier* This report envisages the acceptance by the Federal Government of entirely new responsibilities for the encouragement of research through the creation of a 'National Research Foundation' The scale of operations envisaged may be judged from the rough estimates given in the report of expenditure to be incurred This amounts to $33\frac{1}{3}$ million in the first year and rises to $122\frac{1}{2}$ million dollars in the fifth and is to be divided between the Divisions of Medical Research, Natural Science, National Defence, and Publications and Scientific Collaboration In September 1945, the President sent a message to Congress urging the establishment of a Federal Research Agency Until such an agency is in operation the Office of Scientific Research and Development and the Research Board for National Security will carry on their present functions

The Department of Agriculture, which conducts more research than any other Department, operates through the Bureau of Agriculture and Industrial Chemistry, the Bureau of Animal Husbandry, the Bureau of Dairy Industry, the Bureau of Entomology and Plant Quarantine, the Bureau of Plant Industry, Soils and Agricultural Engineering, and the Forest Service. The work of these extensive interests is co-ordinated through an Administrator of Agricultural Research. The best idea of the scale upon which the Department operates and the value that is attached to research can, perhaps, be obtained by a consideration of the large scale development in agricultural and industrial chemistry initiated just before the war, namely, the setting up of Regional Research Laboratories. These are essentially intended to assist in solving the farm surpluses problems and were established by the Agricultural Adjustment Act of 1938 whereby Congress provided that "the Secretary (of Agriculture) is hereby authorized and directed to establish, equip and maintain four regional research laboratories, one in each major farm producing area and, at such laboratories, to conduct researches into and to develop new scientific, chemical and technical uses and new and extended markets and outlets for farm commodities and products and by-products thereof. Such research and development shall be devoted primarily to those farm commodities in which there are regular or seasonal surpluses, and their products and by-products" [1]

Provision is made in the Act for liberal co-operation with other agencies whether Government, private, universities, scientific societies etc., and the operation of the laboratories is a responsibility of the Bureau of Agricultural Chemistry and Engineering. The four laboratories with their locations and the particular commodities to which they are directed to devote attention are:

Southern Regional Laboratory, New Orleans, Louisiana.	Cotton Sweet Potatoes Peanuts
Northern Regional Laboratory, Peoria, Illinois	Corn Wheat Agricultural Waste
Eastern Regional Laboratory, Philadelphia, Pennsylvania.	Tobacco Apples Potatoes Milk Products Vegetables
Western Regional Laboratory, San Francisco, California.	Fruits & Vegetables Potatoes Wheat Alfalfa

[1] *Regional Research Laboratories Dept of Agriculture* U S Government Printing Office, Washington, 1939, p III.

The Secretary of Agriculture is authorized under the Act to utilize in each fiscal year a sum of $4,000,000 allocated equally to the four laboratories.

All the four laboratories have been planned in the same style and we may therefore take the Southern Regional Laboratory as typical. Building of this laboratory commenced in June, 1939, and was completed by July, 1941. It is a U-shaped four-storey building, 211 ft. along the front and 368 ft. along the sides and cost $1,463,000. A further $200,000 was spent on permanent equipment. Altogether the laboratory represents an investment of some £500,000. The necessary equipment and personnel were secured as the building was being erected and there were employed in it in 1943, rather more than 300 persons. The technical staff, consisting of chemists, physicists, engineers and technologists will number about 175 The whole project has been planned on the basis of an annual operating cost of $1,000,000 and the sum actually made available in the first year of operation (1941–42) was $750,000 These figures, which must be multiplied by four to cover the full scheme, have been given in some detail to indicate the tremendous faith in scientific research in the United States and the pronounced trend towards its large scale increase.

The National Advisory Committee for Aeronautics, referred to earlier, was set up by Act of Congress in 1915, and was modelled on a similar Committee set up in Great Britain. The Committee acts directly under the President, and its members are appointed by him Through this Committee the Government leads and co-ordinates the research in the aircraft industry. Individual firms naturally carry on extensive independent research, but basic research work is carried on at public expense since the Committee has its own laboratories at Langley Field, Virginia, and Moffett Field, California The organization which commenced in a modest way has grown rapidly and, in technical equipment, is now far ahead of the corresponding organization in Great Britain. The Daniel Guggenheim Fund for Aeronautical Research established in 1926, with a capital of $2,500,000, also exerted a considerable influence for a time. The whole fund was expended by 1930, but some of its expenditure had a lasting effect, notably grants to universities for the erection of aeronautical laboratories and the establishment of an airship institute.

Research by Trade Associations

Research by trade associations, in which is included professional organizations such as the Engineering Foundation, the research agency of the combined engineering societies, is normally conducted along a relatively narrow line and for the benefit of a particular section of the community. In this respect they resemble the Research Associations of Great Britain more closely than any other American research organization. Assistance to their members who provide financial support only in return for tangible benefits must of necessity be their first object,

although benefit to the general public is not excluded and is, indeed, a normal by-product of their research and provides an incentive to increased consumption which is generally accepted as one aspect of trade association activities. The problems to be solved by trade association research in America are similar to those of the Research Associations at home. The projects selected must be of general appeal to the industry and must not appear to benefit a single member or small group to the exclusion of others. Relations must be established between the scientific staffs and executives who may include 'rule-of-thumb' operators, highly-trained scientists and widely experienced industrialists.

The National Canners' Association, founded in 1913, was one of the first to engage in technical research. It has a central laboratory in Washington, D.C., branch laboratories in the main canning areas and a travelling laboratory that can be transferred quickly for investigations at any particular spot. This Association was probably early in the field and has been markedly successful because it was able to meet the peculiar conditions required by co-operative research with relative ease. Thus research for the improvement of standard products is non-controversial and the advantages of packing in cans thus lends itself to centralized research. Research on processes and methods is usually best undertaken by trade associations when uniformity of procedure exists and here again the canning industry based on air-tight containers and preservation by sterilization possesses an advantage. The research work of general importance to the industry has therefore covered such items as the prevention of spoilage, the omission of preservatives, linings, particularly lacquers for cans, and the chemical changes occurring during canning and cooking. Both the industry and the consumer have benefitted from these researches and the incentive to increased consumption of canned goods has been provided in full measure.

At the beginning of the war, out of 330 trade Associations listed by the National Research Council,[1] 36 maintained their own research laboratories and at least 54 were conducting technical research in some other way. The size of the central laboratories varied from a laboratory staffed by one scientist and an assistant to one staffed by 116 scientists and their assistants. In all, about 450 scientists plus approximately the same number of assistants were employed in these central laboratories. These figures, if compared with the 70,000 scientists reputed to be engaged in industrial research in the United States, will give a measure of the small part played by co-operative research in the American research economy. The agencies employed, other than central laboratories, vary according to the nature of the problems. Problems of standardization are often undertaken jointly in the laboratories of member firms for the benefit of all. Fundamental scientific work is often organized at a University or a research foundation. In this case the sponsor of the

[1] *Research—A National Resource*, Vol II. Industrial Research. National Resources Planning Board, 1940.

work often does no more than provide the funds, the laboratory chosen providing the facilities, staff, direction, etc. Trial and error methods of research which are sometimes needed are often handed over to commercial consulting laboratories.

In one way or another most of the great industries are represented in the co-operative research field. The Engineering Foundation already referred to, grew out of the five-year plan proposed in 1926 by the Special Research Committee of the American Engineering Council. This plan, which was to cost $335,000, was designed to benefit engineering and agriculture. By 1937, the Foundation had projects under way in the laboratories of fourteen Universities and two Government Bureaux. The Foundation which acts as a co-ordinator of research co-operates with other organizations in the carrying out of projects One such project, on alloys of iron, was sponsored by the American Institute of Mining and Metallurgical Engineering while another, on welding, was sponsored by the American Welding Society and the American Institute of Electrical Engineers.

The petroleum industry also carries on joint research projects on problems of broad interest to industry or to large sections of it. Thus the American Petroleum Institute sponsors a project at the Bureau of Standards on the composition and structure of petroleum; the Pennsylvania Grade Crude Oil Association sponsors a project at the Pennsylvania State College on the composition and processing of Pennsylvania crude oil; and a hydrocarbon research project at Ohio State University is sponsored jointly by a group of twenty-five oil companies and the General Motors Research Laboratories. The Petroleum Research Fund is referred to later in another connection.

Of the industries carrying on co-operative research, two may be selected for more detailed description, namely the paper industry and the textile industry. The Institute of Paper Chemistry at Appleton, Wisconsin, has been operating successfully for a number of years and has been the model for a number of more recently developed co-operative ventures. The textile industry, on the other hand, has had a number of different organizations operating in its field and is only now beginning to co-ordinate their activities.

The Institute of Paper Chemistry commenced its operations on February 1st, 1930, at Appleton, Wisconsin, and was associated from the first with Lawrence College The location and the academic affiliation are important. It was a group of Wisconsin pulp and paper mill executives together with officials of Lawrence College who conceived the Institute in the first place, and within a short radius of Appleton is a compact area of diverse paper manufactures and paper mill machinery manufacture that is unequalled elsewhere in the country. Although, therefore, the Institute was conceived on national lines its strategic location in Wisconsin was a foregone conclusion.

The affiliation with Lawrence College resulted from one of the major

objects of the Institute which was to fill a need of the pulp and paper industry by the supply of trained technical men. In the first ten years of the Institute's existence 170 students passed through the regular post-graduate course. This feature of the Institute is of particular interest since association with teaching institutions, common with American co-operative research establishments, is not usual with the corresponding organizations in Great Britain. The post-graduate training of men for particular industries and recognition of the training by an established college or university is accepted as an essential part of the work to be undertaken by trade associations as with other co-operative research laboratories in America.

The research work carried on by the Institute may be divided into five groups: (i) fundamental research to provide a background for future work; (ii) researches by students for higher degrees, (iii) general problems of industry, *i.e*, applied research; (iv) fundamental research on specific problems of individual mills; (v) confidential research on problems of allied industries. The first three of these are openly available to all members supporting the Institute's programme and are normally published after two years, during which they have been confidential to the members. The fourth, is financed by, and is confidential to, the individual mills requesting the work, while the fifth, which is only undertaken when it is likely to show a benefit to the paper industry, is also confidential to the initiators. The work of students and the work for members is kept severely separate. It is no part of the Institute's policy to provide cheap labour through the use of student services and it is evident that the long-term policy of keeping the training of men and the day-to-day research work in watertight compartments has been well repaid.

At the outset the Institute, which was incorporated as a non-profit organization, was supported by nineteen mills in Wisconsin representing 90 per cent. of the production of that state At the latest available report[1] the support had grown to 100 companies, distributed over the whole country and representing 70 per cent. of the total national production of pulp, paper and board. In the same period the staff has grown from an initial number of three to 150. The first building of the Institute was completed in 1931, the second in 1932 and additions have been made at intervals since then until now the buildings and equipment are valued at about $1,400,000. The Institute has handled 1,100 projects, that is problems requiring actual research work, as distinct from queries which could be answered without extensive laboratory work and which run into many thousands. The researches carried on at the Institute have also resulted in more than 300 scientific publications and 200 patents. Such phenomenal growth and successful application of the principle of co-operative research is eloquent testimony to

[1] *Research by Trade Associations and Co-operative Groups*, Westbrook Steele. *Chem. & Eng News*. 1944, 22, p. 1766.

the possibilities of such a method of conducting research in a comple industry and to the judgment with which the affairs of the Institut have been conducted. It is not surprising that the Institute is regarde in the United States as a model of co-operative industrial research an the underlying principles upon which it operates will well repay stud in this country.

Co-operative research in the textile industry is in a very differen position from that in the paper industry and its problems are being me in different ways. Instead of a single, strong, central research organiz ation there are a number of organizations which until recently hav been independently operated. It is now recognized that the textil industry has lagged behind other industries in its research outlook an expenditure. A report by the National Resources Planning Boar showed that in recent years the average research expenditure amon sixteen major industries was 64 cents per $100 of value added. Textile appeared at the bottom of the list with an expenditure of only 6 cent per $100 or less than 10 per cent. of the average and only 2·5 per cent of the chemical industry's expenditure. This small scale of research ha sounded a warning note and a new and vigorous outlook on research i becoming apparent.

Among the several organizations nominally engaged in co-operativ research for the industry in the past, the chief have been:

The National Cotton Council of America.
The Textile Research Institute.
The Cotton Textile Institute.
The Textile Foundation,

and more recently

The Calloway Institute.
The Institute of Textile Technology.

Of the last two named, the first was organized as a consultin research laboratory in 1943, while the second was incorporated as a educational institution in 1944. It is a non-profit making graduat school admitting not more than fifteen students a year who will b trained for work in the textile industry. It will engage also i research both of a fundamental nature sponsored by the Institute an of a practical character sponsored by, and confidential to, member on a project basis. Support for the Institute comes from textile mill which may become subscribing members under contracts running for a long period of years.

The other organizations have all been in operation for a considerabl time. The National Cotton Council has been chiefly engaged in the pro motion and publicizing of cotton and has spent only about 10 per cent of its income on research; the Textile Research Institute, organized i 1930 as the U.S. Institute for Textile Research, has confined itself largel to a limited number of projects in applied research conducted either i

textile schools or in member firms' premises; the Cotton Textile Institute has been a promotion and publicity organization in which the Research Division was a small section devoted chiefly to bringing to the notice of members, information on practical developments of possible value; the Textile Foundation has been a full-time research organization, staffed by about fifteen scientists working at the Bureau of Standards and financed by a fund provided from the sale of German patents during the first world war. It has been a settled policy, since 1932, that this fund should gradually be liquidated by the steady expenditure of capital and it is now rapidly coming to an end.

As a result of the new and vigorous outlook on research that is developing in the textile industry, steps have been taken to strengthen these organizations. The National Cotton Council and the Cotton Textile Institute have amalgamated by merging, first, their promotional activities and, quite recently, by dovetailing their research activities. The Research Division of the National Cotton Council, located at Memphis, Tennessee, will comprise four sections.

(i) *The Production Research Section* working on cotton from the farm to the mill.
(ii) *The Industrial Investigation Section* working on the needs of textile users and the translation of special requirements that would increase the use of cotton goods, into research problems designed to develop specially needed properties.
(iii) *The Chemical and Engineering Section* working on developmental research designed to translate laboratory processes into commercial practice.
(iv) *The Cotton Seed Section* working on cotton seed products.

The Research Division of the Cotton Textile Institute will, in turn, devote itself particularly to research applied to mill operations. Its main task will be to bring to the mills up-to-date reports on research results and to transmit to the laboratories the needs of mills that research can meet. This will be essentially correlation and co-ordination with little original research involved.

At the same time the Textile Foundation and the Textile Research Institute have reached an agreement whereby they hope to become a central co-operative research association in which the fundamental research now carried on by the Foundation will be extended and added to the development work carried on by the Institute The future programme of the enlarged Institute comprises the following sections:

(i) *Fundamental Research* conducted on all the major fibres, including synthetic, with a view to increasing knowledge and understanding of the properties and structure of fibres.
(ii) *Applied Research* covering research on improved processing methods in all the major branches of the textile industry.

Under this heading will also be included separately financed research projects for one or more members of the Institute.

(iii) *Economic Research* including work on trends and developments in textiles, in other industries, in public activities and tastes. It will provide an information service for members and will be used to influence the fundamental and applied research of the Institute.

(iv) *Information* providing a publication, abstracting and research information service to members.

(v) *Technical Training* by which the Institute will undertake to train in textile science specially selected young scientists with a view to their entry into the industry at a high level.

In order to carry out this programme the Institute is raising a fund by appeals to the industry, sufficient to provide an operating income of $300,000 a year and a sum of $500,000 for building, equipment and facilities. An initial five year plan is being sponsored needing $2,000,000 to carry it through The first material steps have been taken by the acquisition of a building and site at Princeton, New Jersey, to be used as a central laboratory, and agreement has been reached with Princeton University on the training and recognition of students. It will be seen that the proposed method of operating has been modelled closely on that of the Institute of Paper Chemistry.

Even these amalgamations have not been considered to answer fully the problems of co-ordinating the research in the textile industry and a step of considerable interest to British exponents of co-operative research ideas has been the formation of the Inter-Society Council for Textile Research. The first meeting of representatives of the major research groups was held in the autumn of 1943 for the purpose of considering how best their research activities could be co-ordinated and unnecessary duplication avoided. The organizations represented at this meeting were:

The American Association of Textile Chemists and Colorists.
The American Association of Textile Technologists.
The American Society for Testing Materials (Committee D–13).
The Cotton Textile Institute.
The Industrial Fiber Society.
The Institute of Textile Technology.
The National Bureau of Standards.
The National Cotton Council of America.
The Textile Foundation.
The Textile Research Institute.
The Southern Regional Laboratory and the War Food Administration of the U.S. Dept. of Agriculture.

The newly formed Council is intended to provide an inventory of active research work and a clearing-house for all types of textile research,

to steer new problems to the appropriate research agencies and to keep an up-to-date list of all research organizations of interest to the textile industries By this means it is expected that a considerable advance will have been made in increasing the effectiveness of research for the benefit of the industries concerned

The organization of co-operative research in these two industries has been described in some detail as illustrative of the trend of this particular form of research [1]

Possibly the most interesting example of co-operative industrial research is afforded by the Braden Sutphin Ink Company which reported [2] that it carries on co-operative research with three other competitive companies

Independent Fellowship Laboratories

The fellowship laboratory is a form of co-operative research that is peculiar to the United States It is not practised in Great Britain It was born out of an idea in the mind of John Kennedy Duncan in the early years of the century Briefly, Duncan was depressed by the apparent lack of contact in America between science, in which he believed, and industry, on which the future of the country rested. He sought to bridge the chasm by a partnership scheme based upon industrial fellowships at the University of Kansas where he was then professor of industrial chemistry The field and scope of co-operative research conducted by Trade Associations has already been described The development of new products is a facet of industrial research that usually falls without this scope. It approaches the field of private enterprise in research. But, as has been pointed out repeatedly in these pages, the cost of research, even on a single problem, is often very great and therefore outside the scope of a small company It was Robert Duncan's service that he originated a plan that could meet the needs of the small company

While the Trade Association laboratory functions as a central laboratory for an industry, the fellowship laboratory operates as a centralized laboratory for individual companies In other words, it

[1] Other industrial co-operative research enterprises include the American Gas Association Testing Laboratories in Cleveland, Institute of Gas Technology, Chicago (associated with the Illinois Institute of Technology), Sugar Research Foundation, New York (operating a laboratory at the Massachusetts Institute of Technology), National Lumber Manufacturers' Association, American Institute of Steel Construction, National Paint, Varnish & Lacquer Association, Refrigeration Research Foundation, Hotel Association Testing Laboratory, Lithographic Technical Foundation, Nutrition Foundation, Tanners' Council Laboratory. Portland Cement Association, Pineapple Producers' Co-operative Association, California Fruit Growers' Exchange, American Institute of Laundering, American Institute of Baking, Aluminium Research Institute, American Gum Importers' Association, American Pharmaceutical Association, Institute of American Meat Packers, Insulated Power Cable Engineers' Association, National Association of Dyers & Cleaners, National Paving Brick Association, Non-Ferrous Ingot Metal Institute, Underwriters' Laboratory, Utilities Research Commission, Munsell Colour Foundation.

[2] *Industrial Research Laboratories of the United States*, 7th Ed National Research Council, 1940.

gives in research the same service as the central laboratory of a large concern. While, however, the latter works on many problems at the same time for a single company, the former does the same for many different companies. This does not mean that large companies do not support the fellowship idea; they do, and in large numbers. But the fellowship laboratory must often do more than the central laboratory of a firm. The latter receives its guidance on policy from the executive of the firm on which the Director of research may be represented The small company seeking the assistance of a fellowship laboratory may be altogether ignorant of research values or procedure and the laboratory may not infrequently have to advise not only technically, but also in the light of a sound business judgment. Opinions may have to be given not only on how to conduct a particular project but on whether it is a wise project on which to spend time and money, on the necessity for changing the emphasis of a project in the light of changing circumstances; on the time for and kind of publicity for the results. All these opinions can be obtained in a large firm from experts in various departments. If they are to be given by a centralized organization they imply the maintenance of a versatile staff which itself means that the laboratory must be operated on a considerable scale

The best known and most successful industrial fellowship laboratory in the United States, indeed in the world, is the Mellon Institute at Pittsburgh, Pennsylvania, which arose directly from the work of Duncan. Duncan established his first industrial research fellowship at the University of Kansas in 1907 It was for an investigation into the chemistry of baking and the agreement provided for an annual payment of $500 and a sum to be settled later by arbitration. Fellowships were also established to conduct researches into the chemistry of laundering, the constituents of crude petroleum, the relations between the optical properties and the chemical composition of glasses and several others. A wide range of interests were therefore represented even in the early days. So well was the scheme received in fact, and the supply of available researchers so limited, that in 1909 Duncan came to Europe with the object of offering fellowships to English chemists On this occasion he addressed a meeting of the Society of Chemical Industry in London and it is interesting that, in the discussion which followed, considerable doubt was expressed as to the probable success of his proposals [1]

The development of Duncan's plan really dates from 1909, for it was in that year that Andrew Mellon read *The Chemistry of Commerce* written by Duncan a couple of years previously, and was attracted by the plan for industrial research outlined in the last chapter. With his brother, Richard Mellon, Andrew arranged to meet Duncan and they were convinced by the record of his achievements. Arrangements were speedily made for Duncan to come to the University of Pittsburgh

[1] *Journal Soc Chem. Ind.* 1909, Vol XXVIII, p 684.

as the head of a new department of industrial chemistry in which his scheme could be continued. The first industrial fellowships at Pittsburgh came into operation in March, 1911, in a temporary building on the University campus. The cost of the building, its maintenance and a fellowship for the study of smoke abatement were the concern of the founders. The experiment conducted in this way proved completely successful and in 1913 the founders established the Mellon Institute of Industrial Research. A new and permanent building was put in hand immediately and was formally opened in 1915, but unfortunately Duncan did not live to see its completion.

Until 1927, the Institute continued as a part of the University of Pittsburgh but in that year it was separately incorporated and its affairs have since been conducted by its own Board of Trustees. It continues, however, in close association with the University. The interest in pure science was stabilized in 1926 by the formation of a Department of Research in Pure Chemistry. Additional facilities were provided from time to time as the research work increased and the culminating point was reached in 1937 with the gift of a completely new building, which must be one of the finest, if not the finest, structure devoted to the advancement of knowledge in the world.

Time and experience have changed the conditions of the agreements with Fellowship donors but the spirit of the organization remains as Duncan first conceived it Originally Fellows were graduate students who paid tuition fees (or gave teaching time in lieu) to the University and received a higher degree on the basis of the work carried out. The Fellowships are now, for the most part, post-doctorate and the Fellows receive salaries commensurate with their duties as competent research workers. In the early days the University provided space, chemicals, direction, etc., and received in return the Fellows' fees. Now, the expenses of the investigation are paid from the donor's contribution in addition to the Fellow's salary. For this purpose the Institute retains 20 per cent. to cover overhead charges. Fellows have the status of salaried employees and are appointed by the Institute (with the donors' agreement) which is the employer in all cases. All results of the research work are the property of the donor and neither the Institute nor the University with which it is associated derives any profit from the work of Fellows. As in Duncan's time, the agreements still provide for publication of the results of the research but in fact no publication has ever been made without the prior consent of the donor.

The Mellon Institute, by its success and long experience, provides the best example of the method of conducting the Industrial Fellowship plan. It is instructive, therefore, to examine the mechanics and financing of the plan First and foremost the Institute is a non-profit organization "Its business is not to make money but to add to progress through research."[1] Nevertheless it is the boast of its leaders that it is managed

[1] *Behind These Columns* (Dedication book issued in 1937), p 17.

as an orderly business. The buildings having been provided, innumerable expenses remain to be covered. A research laboratory has large overhead expenses in the services that must be provided before any investigation can be brought to a successful conclusion. There must be a library suitable to the class of men who will use it with standard texts, periodicals, scientific literature and reference books of all kinds. There must be well-stocked chemical and apparatus stores. There must be an instrument shop staffed by high class mechanics. There must be a glass blower, office staff, messengers, cleaners, boiler men, stokers, electricians, and a host of other ancillary staff are needed. The Mellon Institute has all these The Library contains more than 20,000 volumes; mechanics, electricians, plumbers and other trades are all represented in a repair and construction section. A highly skilled glass-blower, photographer and draughtsman are also available and an analytical department relieves the Fellows of much routine work.

These facilities must be financed and, as stated above, the Institute retains 20 per cent. of the so-called foundation sum to cover the overhead charges. The remainder of the money is devoted exclusively to salaries and actual expenses of the research The foundation sum represents the estimated cost of the research It is determined by the salaries of the Fellow and his assistants if any, by the cost of needed chemicals, special equipment, travelling expenses of the Fellow and so on, plus the 20 per cent. for overhead charges that is to be credited to the Institute. A typical allocation of the cost of a research project might thus be 20 per cent. for overheads, 60 per cent for salaries and 20 per cent for apparatus and other expenses If pilot plant operations are required these can be carried out at the Institute but are usually covered by a separate budget. But while a part of the financial burden is borne by appropriations from firms financing Fellowships, the true cost of the research is immensely larger than these amounts. For example, in the first twenty-six years of its existence (*i.e.*, up to the opening of the new building) about $11,500,000 was contributed by donors of Fellowships but millions more were expended to augment the work of the Fellows and create a sound procedure of industrial research.

The Institute has always inculcated a liberal policy of publication. Its members have contributed freely to the production and revision of standards and have published more than 20 books and some 2,000 articles in various scientific journals. Upwards of 1,000 patents in the United States have been granted to members and almost an equal number in foreign countries. This impressive record is not exhausted, however, by the research results of Fellows. In keeping with Duncan's original thesis that the work should preferably have a bearing on public welfare, the Institute has carried out extensive work on smoke pollution, chemical hygiene, waste disposal and other investigations leading to the abolition of public nuisances. The Pure Chemistry Department has

carried out work in chemotherapy, dental caries and the development of standards for drugs and medicinal preparations.

The amounts expended on research at the Mellon Institute may be surprising to most but they cannot compare with the untold millions of dollars that have been returned to industry and society through the application of successfully concluded researches, resulting in the creation of new industries, the increased resources of established companies and the employment of thousands of workers. Shortly after its organization a Fellowship was founded to study acetylene. The production of ethylene by a new and cheap process resulted and on this was built a new chemical corporation to exploit commercially the derivatives of ethylene. The synthesis of compounds from the hydrocarbons of petroleum and natural gas, based on the work of this Fellowship, has added more than 130 new chemicals of value to commerce. The chrome-plating of aluminium was developed at the Institute. A vanadium catalyst for sulphuric acid manufacture, organic rubber accelerators, antiseptics, core binders for foundries have all been developed in the Institute laboratories. An immense number of industries have benefited. One great company established a Fellowship in 1927 which was so successful that in 1929 it was decided to erect a company laboratory nearby and to-day a separate research organization has been created, and a large new research plant erected to cope with the developments from that first Fellowship. In one year, 1943, 44 United States patents and 14 foreign patents were granted for inventions from industrial fellowships. Up to the time of the opening of the present building 1,150 industrial fellowships had been established on 279 different subjects.

The success of the scheme and the ultimate development of Duncan's ideal may be estimated from the fact that of about 100 Fellowships in active operation in 1944, 9 had been in existence for more than 25 years, 8 for 20 years, 15 for 15 years and 27 for 10 years. No greater tribute could be paid to the wise conduct of the Institute's affairs and to the solid foundation upon which the Industrial Fellowship system can be built.

The Mellon Institute, although the best known, is not the only co-operative research laboratory of its kind in America. Two other well-known similar organizations are the Armour Research Foundation at Chicago and Battelle Memorial Institute at Columbus, Ohio The Armour Foundation was organized in 1936 for the purpose of rendering a research and experimental engineering service to industry on a non-profit basis. It has no endowment and is supported by contributions, fees for services and royalties on patents resulting from non-sponsored researches. Each project accepted is the direct responsibility of the Foundation, which assigns it to competent specialists drawn from existing staff if possible, or recruited afresh on the basis of possessing the needed qualifications. The Foundation is organized in four sections of chemistry, physics, engineering and metallurgy. No conflict of competitive interests

is permitted and the Foundation does not undertake specific research assignments for more than one sponsor.

The Foundation is affiliated with the Illinois Institute of Technology but leads a separate existence. Its growth has been steady and continuous. In its first year it operated with a budget of $30 000 and a staff of three. The appropriations have more than doubled each year until in 1943 the budget exceeded $1,000,000 and the staff had grown to over 200. Up to that time more than 1,400 companies, associations and government agencies had sponsored projects at the Foundation. Altogether the Foundation had undertaken in the first seven years of its existence more than 200 long-term projects and nearly 5,000 short-term studies. From rooms in an apartment house it has grown to occupy four large new buildings. The staff are appointed on a permanent basis rather than on a limited fellowship scheme and when one project is completed the members assigned to it move on to another problem. Within the organization there is free inter-change of ideas but to outsiders all work undertaken is regarded as confidential to the sponsors and any resulting patents are assigned to them.

Perhaps the most outstanding single result of research at the Foundation is the magnetic wire sound recorder which bids fair to revolutionize the recording industry and which has found immense and mostly secret application during the war. The exploitation of this discovery has now been handed over to the Wire Recorder Development Corporation, an organization founded for the purpose. Like other similar organizations the Foundation carries on research independently of sponsors on problems of general public benefit and principles capable of scientific application. Electron optics, electronics, vegetable oils, recording instruments including the sound recorder already mentioned, and ozone studies fall into this class. Of interest also is a survey project sponsored by the Argentine Trade Promotion Corporation to study the economic resources and industrial developments of Argentina. A field force has been maintained and contact with the main Chicago headquarters has been uninterrupted. This is a new departure in co-operative research and is expected to form a pattern for further industrial and economic surveys on a national basis. In fact, the Foundation has recently been commissioned to carry out a similar survey for Mexico.

The Battelle Memorial Institute was founded in 1929 under the will of Gordon Battelle as a non-profit research institute sufficiently well-endowed to provide independence and continuity. Known particularly for its work in metallurgy the Institute also conducts research on fuels, ceramics, electro chemistry and allied industries. The endowment income has been used to provide plant and equipment and to finance an extensive fundamental research programme and to assist educational projects. The Institute supports fellowships at Ohio State University and elsewhere, but has no formal affiliations with any educational institution.

The bulk of the work carried on is conducted on the sponsorship plan already described by which the out-of-pocket expenses of the projects are borne by their sponsors who, in return, receive exclusively the results of the work including all data and patent rights. The scope of the Institute's work is not confined to technical processes but covers also the economic problems related to it. These cover a wide field, including market research, future trends, and economic repercussions of new technical developments. The Institute commenced operations with a staff of 30 which has now increased to nearly 600. Buildings and equipment have grown correspondingly and now comprise three large blocks with up-to-date pilot plant facilities for large-scale development work. About 1,000 industrial sponsors have been served by the Institute since its inception, some of whom have carried on a continuous programme from the beginning.

An outstanding feature of the work at the Battelle Institute is the manner in which other co-operative associations have made it their headquarters for technical research. Not only does it carry on work for individual firms but for such groups as the Alloy Casting Institute conducting co-operative research for a group of foundries; Bituminous Coal Research Inc., which sponsors work on behalf of some 400 to 500 bituminous coal producers, the Copper and Brass Research Association, the Gray Iron Research Institute and Printing Plates Research Inc. who each sponsor research on problems of common interest to their members.

Regional Research Laboratories

The Regional Research Laboratories are a recent innovation. Modelled generally on the lines of fellowship organizations such as the Mellon Institute, they differ from the latter in having interests circumscribed chiefly by geography The institutions are developments of views widely held that every state in the Union has natural resources, mineral, agricultural or marine, that will remain worthless, and technical resources in industry and educational establishments that will not be used to their full advantage, unless and until new facts reveal their value. The idea inherent in these views, namely the exploitation of regional resources through co-operative research, has not yet been worked out to any great extent but a few organizations are already in existence. These include the New England Industrial Research Foundation, the Southern Research Institute and the Mid-West Research Institute of which the first named is the best known.

Regional planning, the forerunner of regional research, dates back to 1925, when the New England Council was formed to co-ordinate the economic interests and act as a research agency for the States of Maine, Vermont, New Hampshire, Massachussetts, Connecticut and Rhode Island. New England, so defined, covers only 2 per cent of the land area of the United States but contains 8·5 per cent. of the country's

manufacturing industry and 12 per cent of its wage-earners In spite of this apparent concentration of industrial enterprise in a small area, there have been signs during the present century that New England was losing its predominant position A large part of the textile industry, once exclusive to New England, migrated to the South, the boot and shoe industry moved to the middle West; the machine tool industry moved westward to the great new manufacturing centres of Chicago, Cleveland, Cincinnati and Detroit, and the glass and ceramics industries moved away to Pennsylvania and Ohio. The New England Council sought to arrest this downward trend

One of the first acts of the Council was to set up a Research Committee As one result of its survey work a *Directory of New England Research and Engineering Societies* was published in 1939 and listed more than 500 institutions which were available for the solution of problems by the experimental method Meanwhile, in 1938, the Council set up the New Products Committee which surveyed the assets of the region The preliminary work revealed the necessity for more detailed study and four sub-committees were established

The Research Day Committee was formed to carry on an already established tradition of holding meetings and exhibits in important centres for the purpose of focusing attention on research and its methods. Each meeting normally concentrates upon a particular topic, related if possible to the interests of the centre selected The Boston Research Day, for example, held in 1944, was devoted to textiles research

The National Resources Committee was given the problem of investigating the mineral wealth of New England The importance of the work of this committee may be judged from the fact that the last geological survey of the territory was made one hundred years ago when many metals available in New England were of no industrial importance and were therefore neglected

The New Products Committee was to seek to find means by which new industrial products of importance to New England could be manufactured at home instead of being imported.

The Venture Capital Committee was charged with the twin problems of assessing the extent to which lack of capital had prevented the development of industrial enterprises in New England, and of devising methods of making new capital available

The net result of the studies of these sub-committees was to convince the New Products Committee that the technical work required could not be carried on by voluntary committees and that a permanent technical organization was needed It recommended, therefore, the establishment of the New England Industrial Research Foundation The Foundation opened its office in Boston on January 1st, 1942 Like other organizations for similar purposes it is a non-profit institution and income in excess of expenditure will be devoted to the activities of the Foundation. Its field of investigation covers the development of New England

resources, the co-ordination of existing research and engineering facilities and the furtherance of New England in the United States' industrial economy It is governed by a group of Founders drawn from industry, science, education and finance, and operated by a Board of Trustees. Its activities will be essentially those of an industrial research organization, though it is hoped to conduct them with a minimum of permanent staff and to carry out much of its work through the educational and private consulting facilities in the region The main purpose of the Foundation will be to fill whatever gaps there may be and to carry on long-range studies It is expected that a sum of at least $100,000 should be available to provide for the first two years' operations after which it is hoped that the Foundation will become self-supporting through advisory services rendered on a fee-paying basis and through the contribution of technical services to new enterprises. In some cases the fee might take the form of a stock participation in a new company

The Mid-West Research Institute at Kansas City, Missouri, has been established as a non-profit scientific research institution to develop the agriculture, industry and natural resources of the Middle West. The Southern Research Institute at Birmingham, Alabama, has been organized recently to conduct technical research on a contract basis similar to the Mellon Institute scheme. It has started well with a fund of about $400,000 all subscribed by Southern businesses and individuals. The suggestion has been made[1] that the solution of some at least of the post-war problems will be found in these regional laboratories and that they should be extended until each of the forty-eight States has its own laboratory to further its own technical advancement, financed out of public funds. The State-owned laboratories would then carry on research appropriate to the State's resources and the interest of its people, as well as provide facilities for small businesses to get centralized co-operative facilities for their research projects.

University Research Foundations

The University research foundations are a development of the last twenty years and it is by no means certain yet that it is a desirable development. The general purpose of the organizations is to provide a business-like method of handling contractual research in the University laboratories where it serves the double purpose of training students in actual industrial problems and permitting centralized co-operative research rather similar to the Fellowship laboratories of the Mellon type The first of these ventures was the Wisconsin Alumni Research Foundation which started in 1925, with a capital of $900, and the Steenbock patents for the ultra-violet irradiation of foodstuffs to develop desirable vitamin content characteristics. These patents contributed in no small measure to the success of the Foundation, since they have

[1]Wheeler Mchillen, President, National Farm Chemurgic Council, *Chem. & Eng. News*, 1944, p. 519.

provided a steady income that now exceeds $1,000,000 a year. The funds so provided were to be used to further research work in the University. The Foundation is now independent of the University except that in the event of its being wound up its assets revert to the University. Since the original patents, others have followed from the research work but only a very few bring in any income. The royalties go to swell the capital endowment and are not to be used as income until the endowment fund reaches $10,000,000 which will shortly be reached, if, indeed, it has not already done so.

The Purdue Research Foundation, associated with Purdue University, Lafayette, Indiana, was established in 1930. In this case, the student research, particularly in the department of chemistry, is based on industrial projects. The Foundation commenced with a substantial capital endowment provided by the alumni and further gifts have come since to swell the fund. The operating income is derived from the returns on a total endowment of $3,000,000 together with income from royalties on patents from the research work.

Ohio State University Research Foundation was established in 1937, as a non-profit corporation, to act as the controlling and administrative agency for research work conducted in the University laboratories on a contract basis. The Foundation also handles all patent work on behalf of the University. In the short time that it has been operating, it has acquired many valuable patentable inventions and has licensed manufacturers under them. The income received from the royalties and any other earned income is converted to a research reserve to further new co-operative programmes and to foster fundamental research. In 1944, the Foundation made grants amounting to $37,600 for the latter purpose. Massachusetts Institute of Technology also has a Research Foundation and recently announced organizations of the same type are connected respectively with the University of Texas, the Stevens Institute of Technology, the University of Louisville, Wichita University, Temple University, Philadelphia, and the University of Chattanooga. The announcement of the formation of the Stevens Research Foundation was made at the Alumni Association's annual dinner early in 1944 and indicated that it would follow the general plan of such organizations. It is to be a non-profit corporation, established to carry out scientific and technical research in connection with the Stevens Institute, and is empowered, among other things, to examine and develop inventions and to assist in obtaining patents for them which are to be vested in the Foundation. Research work is to be carried out independently and in conjunction with the Institute and also with industry on a contract basis. All the specialist research laboratories of the Institute have been placed under the control of the new Foundation and a close relation is to be maintained between the staffs of the two. It is expected that the Foundation's main work will be in fields of fundamental importance of general interest and value in which the problems may take several years to solve.

It is too early to say what permanent success these organizations will achieve or what will be the ultimate effect on the University teaching and the calibre of the students, but already about twenty Trade Associations, besides individual firms, are using University fellowships as a method of carrying on research on problems that are sufficiently well defined to be tackled on an individual basis

Other Co-operative Developments

It has already been pointed out that the United States has been uninhibited in its search for sound co-operative research organizations. Beside the types already discussed there are a number of more general developments of interest Some of these are based on constitutional procedure that is not new. The National Research Council, for example, is an undertaking founded during the first world war under a Charter granted to the National Academy of Sciences during the Civil War. The Council is an operating agency of the Academy, and its work was so satisfactorily performed that in 1918 it was given permanent organization by President Wilson to stimulate peacetime research and to promote co-operation in research. It now has seven divisions of science and technology and a division of foreign relations. In 1940, the National Defence Research Committee was formed under its auspices, and a year later the more comprehensive Office of Scientific Research and Development.

Another organization set up during the last war is the Chemical Foundation founded by F. P Garvan who, not a scientist himself, believed in the value of research The Foundation was originally set up to enable American industrialists, in co-operation with each other and the Government, to establish a dyestuffs industry. An Amendment to the Trading with the Enemy Act in the last war, enabled the alien property custodian to take over about 4,500 enemy owned chemical patents and the problem then was to originate an organization to handle them to the best advantage. The Chemical Foundation was the result. This was to be a holding corporation, not operating the patents itself but issuing non-exclusive licences to persons wishing to use them in a competitive chemical industry. The important and permanent aspect of the Foundation's work, from the point of view of research, was the provision that all surplus income should go to the support of research. Garvan himself took charge of this side of the Foundation's business and as rapidly as money became available he used it to further research projects and the education of the public in its importance. The paper research laboratory at Savannah, Georgia, was made possible by funds from the Chemical Foundation and in 1934 Garvan took a large part in organizing another wide-visioned development—the Farm Chemurgic Council—for an all-out attack upon agricultural problems.

A feature of American co-operative developments is the frequency with which they have been associated with the exploitation of patents.

The Wisconsin Alumni Research Foundation and the Chemical Foundation, to take two widely different examples, were both established on the income from patents. It is the usual procedure for the University Research Foundations to handle all patent work for the University, thus relieving academicians and scientists of the necessity to be concerned in the exploitation of useful developments Even where such a Foundation does not exist, a patent working organization may exist as, for example, at the University of Illinois which has a University Patents Committee to which the researchers hand over their results for exploitation, receiving in return a proportion of the derived income, the remainder going to the University for the furtherance of research work. The exploitation of patentable material by Trade Associations has also led to the formation of specific organizations for the purpose Thus the National Lumber Manufacturers' Association founded an auxiliary in 1933—the Timber Engineering Company—which was constituted to develop and license certain patents The Company is controlled by the Association but operates separately and produces a combination of research, development, and business activity that has proved very successful. The income from the licensing of the patents provides funds, as in other cases, for additional research

Another co-operative development of great interest based on the exploitation of patents, is the Research Corporation which, in its modern form, acts as a patent holding and development organization for several academic institutions doing for each what the Patents Committees described above carry out in individual cases The Research Corporation was organized in 1912 out of the work of Professor F G. Cottrell who worked at the University of California on electrical precipitation methods. Once the value of his process was established he founded the International Precipitation Company to act as a holding corporation for patents. The Western Precipitation Company was organized to carry out the actual engineering work in the Western states, in 1911 it acquired the parent company, and in 1936 the name was changed to Western Precipitation Corporation, which is therefore a research and development enterprise linked in one area to a constructional unit It was from the International Precipitation Company that the Research Corporation was formed When the Western Precipitation Company was set up, Cottrell and his associates offered their patent rights for the Eastern States to the Smithsonian Institute as an endowment for research The Institute did not wish to be direct participators and the Research Corporation was therefore organized to exploit the patents and pay over any profits to the Institute and such other institutes as the Directors selected. The idea behind the corporation was that it would be able to keep academic institutions in touch with industrial needs without their becoming involved in business details and would also be able to develop and commercialize useful inventions evolved by men in academic positions. The Corporation would arrange licences to manufacturers on fair terms

that would encourage them to take up the inventions, and at the same time it would be accumulating funds to foster further investigations. Since it pays no dividends, the Corporation owns all its own stock and the Board of Directors, 50 per cent. business men and 50 per cent. scientific or academic, is self-perpetuating. It has two well marked functions, the first, commercialization of inventions and the second, granting of funds for research work In its first capacity it behaves like a business house and in its second, like an endowed foundation. Research Corporation is an experiment in co-operative research based on the idea of a semi-public organization working for a number of institutions. It has agreements to handle the patentable inventions of Massachusetts Institute of Technology, Princeton University and Columbia University among others.

A recent gesture reminiscent of the earlier gift of Cottrell to the Smithsonian Institute, has produced the Petroleum Research Fund. This is a trust created by the owners of the Universal Oil Products Company for the benefit of the American Chemical Society. The Universal Oil Products Company was organized on the basis of cracking patents owned by Jesse Dubbs and for the purpose of developing them. A laboratory was established at Independence, Kansas, which was so successful that in 1922 a new and larger laboratory was built at Riverside, Illinois. Universal Oil Products Company has always been a research and development company owned by a group of oil companies—Phillips Petroleum Company, Shell Oil Company, Standard Oil Company of California, Standard Oil Company of Indiana, Standard Oil Company of New Jersey, The Texas Company and N. V. de Bataafsche Petroleum Maatschappij. It is itself, therefore, an example of co-operative research although organized as an independent company As a business concern the company would be subject to taxation, but as a foundation operating under the American Chemical Society the money previously paid in taxes becomes available for research

Like the Smithsonian Institute earlier, the Society could not accept the responsibility of becoming the direct owners of the Company and a trust agreement was therefore drawn up whereby the Society becomes the beneficiary of the income while being relieved of any responsibility for control or operation. The Guarantee Trust Company of New York assumes the responsibility of the trustee. The formal signature of the agreement was completed on October 26th, 1944, and the Petroleum Research Fund was established. The gift thus made to the Society runs into some $8,000,000 to $10,000,000 with an annual income approaching $1,000,000. The agreement provides, among other things, for the following

(*a*) All the funds paid to the Society are to be used for advanced scientific education and fundamental research in the petroleum field.

(*b*) None of the results of any aided research may be turned to profit by the recipient of the aid or the institution aided.
(*c*) Every patent resulting is to be dedicated to the public, royalty free.
(*d*) The object of the Fund is the advancement of public welfare.
(*e*) The recipient of the income must not be a propagandist organization nor must it seek to influence legislation
(*f*) The work of the Universal Oil Products Company in research, development and the ownership and licensing of patents, processes and patent rights in the petroleum field is to continue

The Industrial Research Institute

One of the latest moves in the American quest for the best organization of research is the formation of the Industrial Research Institute. This Institute is affiliated with the National Research Council and its purpose is to promote, through the co-operation of its members, improvements of methods and economy and effectiveness of management of industrial research Research organizations have peculiarities that make them difficult to fit into a normal business management and little information is available to enable industrialists to organize and manage research in such a way that useful results are obtained with the greatest efficiency and economy. The Industrial Research Institute seeks to change all this. Its members meet for discussion about every three months and its staff conducts surveys and investigations on a variety of subjects connected with research management, such as the selection of projects, relations with universities, personnel control, research budgeting and research advertisement. The members of the Institute come from different industries and full advantage can therefore be taken of the possibility of generalizing the successful experiences in individual industries. It thus provides a source of up-to-date information on the problems of organization, management and policy facing industrial scientific research

VII

THE FUTURE OF CO-OPERATIVE RESEARCH

THE PUBLICITY ATTENDING the advances in science during the last five years have made unnecessary any defence of research Radar, that guides homing planes, directs guns, locates enemy aircraft and may all but replace the sight of blind men; penicillin, the inexplicable, antibiotic

offspring of a fungus that has already made commonplace, cures that would have been miracles five years ago; D D.T., which after concealing its existence modestly for half a century within the pages of scientific reference books, broke forth to free armies of the plague of lice and, at its first essay, a city from the scourge of typhus; these are the advertisements of scientific research, more potent than neon lights, high-pressure salesmanship or the staid pens of defensive scientists. The whole world is aware of the forces that may be released by research. It has become a magic word, the 'open sesame' of the new age. Ten years ago Sir Henry Tizard said:[1] "Everyone believes in scientific research without knowing quite what it means. Thirty years ago a Member of Parliament advocating the need for scientific research would as likely as not have emptied the House, to-day, I should be inclined to say of the House of Commons that it is not sufficiently critical of expenditure on research, because its faith is greater than its understanding." If that was true ten years ago, how much more so to-day.

So research will go on. In peace or war it shows no signs of a slowing tempo but rather a geometric acceleration. Research breeds its own kind and the breeders are ever busy forcing the pace. But with the widening influence of its major discoveries comes the realization that its cost is increasing in direct ratio to its rate of growth. Research, having become an expensive undertaking, it is not surprising that there has been a swing away from independent research and towards its co-operative counterpart Because of the urgency, the cost and the variety of the demands, co-operative laboratories must grow in number, size and diversity.

Ecology of Co-operative Research Laboratories

The co-operative method in industrial research is an inevitable growth, but according to the most elementary factors of survival it must fit its environment if it is to continue in the struggle. This fitness can neither be regulated nor compressed within the confines of a single pattern The development of specific co-operative systems at home, in other parts of the Empire and in the United States underlines the diversity of approach to the central idea that is possible. There must be and there will be variety, differentiation of function and method, degrees of freedom to be differently exercised.

The co-operative research association has established itself as the system peculiarly suited to Great Britain, just as the fellowship institute has established itself as the predominantly American pattern. Apart from the abortive experiment at the University of Bristol after the war of 1914, no serious attempt has been made in Great Britain to explore the possibilities of the latter system and it may well be that its absence is a weakness in the national research organization. Its success in the United States shows that it has the seeds of fitness to environment within it, an environment that may not be so lacking in this country as has

[1]Presidential address to Educational Science Section, British Association, 1934.

hitherto been believed. To experiment with this type of organization will need courage, patience and resources and the last in particular is not likely to be easily arranged. The Department of Scientific and Industrial Research is already fully occupied with the expansion of the research associations and even if private benefactions were forthcoming it seems desirable that such an enterprise should not be isolated from the main stream of research administration. Without such an experiment it is difficult to see where the very small industries, important in themselves, but incapable of supporting research associations of an economic size, are to obtain the fundamental investigations necessary to their continued progress. In one sense the suggestions for a planned industrial research site at Leatherhead, where a number of research associations separately financed and reasonably independent will share common services such as library, instrument workshop and conference hall, is a step in the direction of the fellowship institution which is, or may be, in essence a number of small research associations sharing the common expenses that go to make up overhead charges while paying their way for actual work performed. In addition to the extension of the research associations now in active progress a wholehearted experiment on fellowship laboratory lines might with advantage be undertaken

Size of Co-operative Laboratories

With the increase in the numbers of research associations something must be said about their size. Almost without exception they have in the past been too small. Too little money spent on research is wasted money. There is an economical minimum at which the results begin to justify the expenditure. Below this figure too much is expected from research and too long must be taken over it to make it effective. It must not be supposed that a simple formula exists which says that if one man can produce results in a week, seven men can produce them in a day. Research is no sausage machine that turns out the products in proportion to the speed of the handle but it is a fact, nevertheless, in research as in other work, that given proper direction increases in output at or near the minimum more than balance increases in staff. At the other end of the scale, the reverse is true and the large laboratory may become economically unwieldy so that further increases in staff are not reflected in increased output

Where then lies the happy mean? It will almost certainly be different for different industries and even for different laboratories in the same industry. Perhaps the best guide is to consider the laboratory in relation to the director. When it becomes so large that he can no longer effectively exercise a personal influence on the problems being investigated, it may with reasonable confidence be assumed to have passed its economic limit. According to R. E. Slade[1] the most efficient

[1] *Nature*, 1945, Vol *155*, p 280

sized industrial chemistry laboratory houses a staff of about 500, of whom 60 to 100 are scientists. Beyond this size it is preferable to start a second laboratory rather than to adopt the easy course of continuing to enlarge the first. Problems of this nature have not yet become acute in the research associations of Great Britain but they may well do so if the high expenditure envisaged for some associations, notably the British Coal Utilization Research Association and the Iron and Steel Research Association, are realized. The difficulties of organization, staffing and directing may well lead us to reflect whether the sudden expenditures of such large sums of money are wise or likely to be fruitful. The finest fruit does not necessarily grow on large trees and indeed the largest tree, all wood and leaf, may do nothing more than kill the vegetation in its neighbourhood and provide a soporific shadow beneath its branches. Research associations, like trees, should progress steadily towards maturity with much attention during their growth to their shape and ultimate size.

Large scale expansion of co-operative research associations is inevitable if the laboratories are to become adequate to the needs of industries. But they must not be too large and there seems but one answer to the over-large research institute, namely, a hiveing-off to form a second centre. After all, the ultimate in research policy is an individual economic laboratory in every unit of industry. Alas this is impossible, but if it were not nobody would grudge it. There is no reason to be disturbed at two or even more central research institutes in the same industry. Let every industry support as much research as it conveniently can and as the drain on the country's scientific resources will stand. In one sense this is already effective in groups of industries. The textile industry now supports three research associations for cotton, wool and linen respectively, and may soon support a fourth, for rayon. True, cotton, wool, linen and rayon are usually regarded as separate industries but they form between them the single great textile industry of Great Britain

Co-ordination of Co-operative Laboratories in Related Industries

The increase of research by the increase of the number of institutions may perhaps lead to one obvious disadvantage. Since one of the recommendations of the central research association is that it avoids unnecessary duplication, precautions will have to be taken to see that the multiplication of institutions does not result in repetition of work or competition along the same lines. Scoops by laboratories have sometimes been given as large a place in science as by newspapers in journalism. The mere possibility emphasizes the need for a co-ordinating council to apportion work and responsibility between laboratories to the best effect. The existence of groups of related industries each with its own research association working sometimes on very similar problems, has already made evident the desirability of such a scheme. It will

be remembered that in describing the co-operative research in Great Britain it was found appropriate to do this by groups of industries—the fuel and power industries, transport industries, textile industries, food industries, metallurgical industries, and although the majority of research associations were born and grew up independently, they now for a large part fall into groups with a natural community of interests

The idea of centralized councils is not recent nor original The Department of Scientific and Industrial Research introduced it for co-ordinating work in fields of national importance and has set up Boards for the overseeing of all work in related fields such as Fuel, Food and Building There has been of late a renewed interest in this development and proposals have been made for central councils in several different industries. The Institution of Electrical Engineers' Post War Planning Committee has proposed a British Electrical Research Board to which the industry would disclose its scientific research activities, and the Institution of Radio Engineers has made a similar proposal for a Radio Research Board The theme has recently been developed by Seligman[1] for the metal industries by the suggestion that a Metallurgical Research Council should be established. All these plans have much in common They all stress that no provision is now made for the broad correlation of research efforts, everything being left to such co-ordination as individual units see fit to introduce. They all envisage the collection and distribution of information on the total research effort in related fields and for the most part they go so far as to require disclosure of researches in progress to the central organization which will have authority to redistribute the work, when it thinks necessary, to laboratories more suitable for its prosecution. Surveys of needs and facilities, proposals for, and organization of, new research and maintenance of foreign contacts are all considered appropriate to the functions of such co-ordinating organizations In spite of the danger that we may over-organize our efforts and waste much valuable potential research personnel on unproductive administrative labour, some form of correlation of the work in related fields seems to be desirable. The general impression is that many industries are now awake to the desirability of establishing for themselves something similar to what has been provided for agriculture in the Agricultural Research Council. What form the administrative councils will ultimately take is not yet clear, but it seems that a simple and effective beginning without overmuch waste of talent might be made by the setting up of small councils of research directors working in related fields. By meeting and comparing notes at reasonable intervals —perhaps yearly or half-yearly—these might achieve a degree of co-ordination of the efforts of their respective institutions that would not be incommensurate with the time and talent represented at the meetings

[1]R Seligman. *Engineering*, 1945, vol. 160, p. 84.

National Co-ordination of Research

Over and above these suggestions for the co-ordination of the research work of related industries there has also arisen a demand for co-ordination on a national scale, best expressed perhaps by Dunsheath in his desire for a "live central co-ordinating secretariat which would command respect in the industrial world" [1] Well-defined proposals have emanated from the Federation of British Industries[2] and the London Chamber of Commerce [3] The former, after expressing the conviction that, in the absence of research carried on by every unit of industry, research associations or other centralized institutions should be encouraged in all industries, went on to refer to the desirability of establishing a Bureau of Industrial Research. The Bureau, it was expected, would publish a Year Book giving a description of current British research achievements and would also engage in a campaign of education in, and publicity of, research affairs. The plans of the Federation appear to have mellowed a little with time but arrangements have been made since the publication of its original report to shape something from the Industrial Research Committee to serve the purpose in mind. The Committee has been strengthened and converted into a permanent standing committee with its own secretariat, a scheme that is now considered to be more practicable than the originally proposed Bureau The Federation will not engage in research but through its permanent Committee and in collaboration with other interested parties it will promote the interest of industry in research and its application. The objects of the new Industrial Research Committee include the stimulation of the national interest in research and its industrial application, the encouragement of industry to devote increased resources to its promotion; the encouragement of post-graduate research by the provision of funds; the facilitating of co-operative research with special emphasis on the needs of small industries; and the creation of a system of liaison with reference and similar libraries. A considerable part of the Committee's work will consist also in the extension of research publicity through press releases and other methods

The London Chamber of Commerce report was concerned with the need for intensified research to restore the export balance for which it concluded there were three essentials, centralized and planned direction of research, increased funds for research, and larger, better trained and better paid research personnel. For the first of these needs it proposed a Central Research Board similar to, but differently constituted from, the Advisory Council of the Department of Scientific and Industrial Research and with different terms of reference. The objects of the Board would be to encourage private firms to disclose discoveries not

[1] P Dunsheath. Llewellyn B. Atkinson Memorial Lecture. Royal Society of Arts. February 1st, 1943

[2] *Industry and Research.* October 1943 Report of the Industrial Research Committee of the F B I.

[3] Report of the London Chamber of Commerce on Scientific & Industrial Research, January 1944.

necessary to their own use and the Board would make grants to cover the cost of such researches with the aim of encouraging their completion. It would encourage the use of research associations and have the right to intervene in their work and require them to carry out fundamental research on problems of national importance. It would also require greater activity from research associations which appeared to be unequal to their responsibilities. For this purpose it was assumed that the Board would have at its disposal public funds which would enable it to offer or withhold support at its discretion It would endeavour to ensure that the results of academic research were brought to industrial application in the shortest possible time, for which purpose it would appoint a highly qualified secretariat. When poor quality or high price were proving obstacles to the expansion of trade in foreign markets the Board, with the facts before it, would endeavour through technical research to overcome the disadvantages. Applications for grants in aid of academic research would come through the Board and public opinion would be aroused by all the resources of publicity through the press, radio and cinema. It was considered that the plan would need the reorganization of the Department of Scientific and Industrial Research and that the Board itself would be a statutory body having freedom of action within the terms of its Charter, something on the lines of the British Broadcasting Corporation although it was envisaged that it would be directly responsible to Parliament through a minister, probably the Lord President of the Council. The Board, as proposed, would consist of five industrialists, four scientists and three representatives of labour, and be presided over by a highly paid independent chairman supported by a strong, active and whole time secretariat.

An independent experiment in the development of co-ordination in research work and its publicity, commenced in 1944 with the formation of the Manchester Joint Research Council fostered by the University and the Manchester Chamber of Commerce. The scheme was initiated following upon the delivery of four public lectures in the city by prominent scientists under the general title of Science and Industry. The local research association of the cotton industry and the Department of Scientific and Industrial Research are also represented on the Council, which aims to bring research and industry together. A full-time executive officer has been appointed and although little information is so far available on its activities, its outlook and determination to become a force between industry and the laboratory was expressed by the chairman's statement, at its first meeting, that the Council "must try to be something more than a debating society and to achieve something of practical value to scientists and industrialists".

International Co-ordination of Research

The next step in the co-ordination of scientific research must be international in scope and some tentative moves have been made in

this direction The war has done a great deal to strengthen the means of collaboration. Empire co-operation has proceeded smoothly so far as war problems are concerned. Since 1940, the Dominions have maintained scientific liaison officers in London and these, together with representatives of the Royal Society, published a Report in 1943 of discussions they had had "to secure scientific co-operation in settling the emergency problem of the immediate post-war period and to ensure that the most should be made of our common scientific resources after the war for improving both scientific knowledge itself and the life of the peoples of the Empire". Imperial co-operation in research is nothing new as will be appreciated from the chapter on co-operative research in the Empire, but it needs to be greatly extended. The work of the Imperial Institute, Imperial Agricultural Bureaux, the Colonial Products Research Council and the Dominions Liaison Officers indicates the possibilities in this field of Imperial effort.

Imperial co-operation should not be exclusive but rather should be a milestone in international co-operation and this, too, has seen its genesis. A British Central Scientific Office was established in Washington in 1940 to co-ordinate the exchange of technical information and workers between Great Britain and the United States, and a little later the United States reciprocated by setting up in London a branch of the Office for Scientific Research and Development. The United States and the British Central Scientific Office also maintained close relations with the Canadian National Research Council. The British office also had Dominion representatives attached to it and the essential Imperial co-operation was ultimately recognized in the name, which was changed to the British Commonwealth Scientific Office. This organization now co-ordinates the work between Great Britain, the Dominions and the United States. It is an augury for the future that this effective organization is to be continued in a permanent form.

The Philosophy of Co-operative Research

So much for the overhead organization of co-operative research. But organization alone is not enough. Equally important for its future is the development of a philosophy. The importance of a natural and indigenous growth has already been stressed. Research, whether co-operative or not, must be no hot-house plant to fade and wither at the first blast of criticism or the cold air of disappointment. Criticism and disappointment there must and will be, and to a healthy organism they may act as tonic stimulants, but the healthy organism can only flourish in its natural environment. Co-operative research must be conceived on the grand scale. Industries, not firms, are the units in which it deals and it is on the appreciation of this scale that the spreading flush of healthy life will depend.

Acceptance of this scale of operations, which is as much a matter of outlook as of potential size, will dictate the future maturity of co-opera-

tive research. The successful research associations of the present day are those that have seen and acted upon the implications of this vision. Too many research associations lead stunted lives, stultified by their own usefulness. *Ad hoc* enquiries, 'trouble shooting' investigations and hand-to-mouth acceptance of immediate problems are occupying their time and effort and preventing them from envisaging from the mountain-top of a properly scaled vision, the promised land of programmed fundamental research into which they should enter. Fundamental research is the basis of future applications and while individual firms are rightly struggling with their own daily problems, it is the privilege and the responsibility of the co-operative laboratory to look beyond the turmoil of the present rapids to the distant country through which the same river must flow broadly, strongly and smoothly.

Co-operative laboratories, if they are to justify the faith in them, must be fundamental in outlook It must be an ingrained part of their philosophy. And industry must support them in this attitude. It is both unfair and unwise of industry to demand immediate returns. By so doing, industry is living not only on its own capital but on the capital wisely invested of generations before. The practical results of to-day are the products of the fundamental dreams of yesterday, brought to fruition by a long, arduous and often disappointing road. It is industry's duty to share the long road and its disappointments and not to leave it to be trodden alone, fearfully and perhaps secretly, by the research workers.

But if more fundamental work is necessary in co-operative research organizations, application and development must not be neglected. The fundamental research, when complete, must be applied to be of value to industry. Large units may often be in a position to make their own applications but the small units are then at a disadvantage, though admittedly not so great a disadvantage as if there were no research association. The gap between the opportunities of large and small units is lessened further if the research association has an active liaison section carrying its results and explaining them to every individual in the industry The gap still remains, however, and can only be bridged by the research association itself with the aid of a strong sense of the development of its fundamental discoveries. When the research association carries out its own development and application work, no gap remains among the members supporting the association other than their financial standing and their initiative in taking up new developments, and these are normal commercial risks. Besides this question of equity between the supporters some industries, particularly the older ones, are not in a position to do their own development and unless the research associations in such industries do it, it will not be done, and the fundamental work will be wasted.

In the years between the wars the neglect of new inventions was the cause of great loss. The application of fundamental research was

lacking and all the advantages which might have been possessed by a country having unsurpassed scientific quality were lost to nations which paid more attention to the application of research to industry, often enough to research originated outside their own borders. Future industrial techniques will be different from present ones, but unless this country pays attention to the development work necessitated by its own scientific research, it will flounder helplessly along in the wake of more progressive countries employing the new techniques.

The degree to which a research association should indulge in the development of its discoveries to the point of industrial application must be a matter for individual consideration, bearing in mind that development is at least as expensive as fundamental research and that industries are differently equipped to undertake their own industrial exploitation. Small research institutions will almost certainly be unable to conduct development work independently and some joint scheme for geographically proximate institutions might have much to recommend it. Alternatively, government assistance in the shape of one or more establishments equipped to assess the value of potentially important developments and to take over those judged to be of probable success, may provide the solution of this problem

One difficulty that arises with all research associations, both large and small, is that they are non-profit organizations, which literally means that while they can make losses they cannot reap the benefits in the shape of profits of the successful development of research ideas. One method that has been adopted to overcome this technical difficulty is the formation of a separate commercially operated development company. One or two research associations in Great Britain are already adopting this procedure and it will almost certainly spread among the larger ones. In the United States, the method is being successfully exploited by the Armour Research Foundation through its Wire Recorder Development Corporation, and by the National Lumber Manufacturers' Association through its Timber Engineering Company.

Staffing the Co-operative Laboratory

In the long run the outlook, and hence the output, of a laboratory depends on the director Too much time and energy cannot be expended in finding the right man. This has certainly not been sufficiently appreciated in the past. It goes without saying that a director should be himself a leader in research. He should have had a sound training and have proved that he is able to originate and plan researches and carry them through to a successful conclusion. But he must be more than a scientist, he must be a competent administrator. The growth of the research team idea has put a premium on administrative ability. It is a commonplace that great scientists are often poor administrators and it follows clearly that a great scientific reputation alone is no assurance that a man will be a good research director. The field is

therefore narrowed; scientist and administrator in one becomes the object of the search. But even this is not enough, for a director of co-operative research must be, in addition, something of an industrial statesman He must have energy and enthusiasm tempered by sound judgment. He must have an understanding of men and be able to inspire his staff. He must possess a flair for interpreting results in the laboratory in plain language, free from bias and unswayed by his own or other people's known or suspected interests. He must recognize the needs of industry before their symptoms are apparent to other eyes and must see clearly the road of attack to meet them. No wonder Sir Lawrence Bragg wrote in the *Times*[1], "We lack a sufficient number of inspired leaders in industrial research". These men are rare; they must be; there are too few of them in any walk. Fortunate is the research association that finds such a man. He cannot be esteemed nor paid too highly.

In addition to the director, a matter of prime importance is the selection of the staff for focal research stations. This is an important consideration in any laboratory, but in the co-operative scheme it assumes frightening proportions. So much depends on a co-operative research institution. The future of an industry may be bound up with the success or failure of a single laboratory, and the faith of men who have collaborated to establish it may be sorely tried, or even lost by the ineffectual efforts of their creation. The men who found co-operative research institutions must therefore assume a heavier responsibility than the subscription of money Granted that research is expensive, it is not enough to spend money. Long and careful planning must go into the erection of an organization that will avoid waste and disappointment. Size alone will not assure success. It may even make for failure. Unless the organization is efficient, its waste and disappointment will increase with its size. Time and thought must therefore be expended liberally by the founders if their organization is to live up to their expectations.

Mere size meets its first problem in the difficulty of staffing. A large organization with a second-rate staff is a heavy liability Research, as so many other fields of endeavour, is limited in the long run by the quality of the men engaged in it. A perfect organization, designed on paper to run on the most silent of oiled bearings, will be unproductive if the men do not match it The lack of a sufficient number of trained men was a difficulty faced by the Department of Scientific and Industrial Research in its earliest days and was met, then, by the establishment o grants and awards to encourage the training of more, and more suitable, research workers. The recent expansion of research activity has led to a similar situation of shortage of the right types for filling the important positions of research workers in co-operative laboratories. It has been recognized by many and some steps have been taken already to effect a cure. Imperial Chemical Industries Ltd., Unilever Ltd., and the

[1]December 2nd, 1943.

British Cotton Industry Research Association, to quote examples, have announced the provision of University fellowships to encourage training in research methods. Whatever the cost and however it is done, co-operative research associations must be adequately staffed if they are not to become heart-breaks to scientists and industrialists alike.

Financing Co-operative Research

A question that is bound to arise in any discussion of the expansion of co-operative research is that of finance. Individual firms, if interested in expanding their research activities, have no interests to consider but their own and an examination of their resources will indicate the extent to which their research interests can be gratified. Co-operative organizations are not in this class. They have, at the outset, no resources and during their existence resources sufficient only for their immediate requirements. The necessary money must be raised from sources whose interests must be aroused for the purpose.

There are three possible sources of finance for the co-operative laboratory, Government, industry and endowment. Of these, the third has been growing steadily less in recent years as the income from investments has decreased. It is doubtful whether such munificent benefactions as those of Lord Nuffield to Oxford, Lord Austin to Cambridge, Lord Brotherton to Leeds or the Wills family to Bristol can be expected in the future. This leaves only Government and industry as possible sources of large-scale revenue. It is from these two sources that institutions such as research associations have drawn their support in the past and must continue to do in the future, but the contribution from each must be greatly increased if any expansion on the scale envisaged is to be achieved.

There is good ground for arguing that the proportion of research expenditure borne by the State, either by direct grants or by taxation relief to contributing industry, should be increased substantially. Only so can the general consumer share in an investment which ultimately pays its chief dividends to him The producers certainly reap the immediate benefit of research results, but it may be a very temporary benefit and in some ways a costly one, for the exploited research results may make plant, processes and products obsolete with a consequent loss of capital On the other hand, the consumer of the ultimate article who may have contributed little or nothing to the capital expenditure is the real, permanent and major beneficiary Decreased costs, wider distribution, increased variety are the benefits conferred on the consumer by the intensive application of research It is reasonable, therefore, to ask that the consumer contribute a fair proportion to the cost of the researches carried on for his benefit and there is no easy method short of State assistance on a large scale that can bring the ultimate consumer's contribution into relation with his return.

Industry, however, would not expect to be exempted from its con-

tribution. It has shown in the past how well it realizes its responsibility in this direction, but the willing horse has been worked to the point of exhaustion while others have enjoyed the same lush pastures. For an equitable distribution of the load on the one hand and the assurance of continuity of resources so necessary to successful research on the other, it is difficult to see any escape from the principle of the statutory levy. By this means, all firms within the industry share the burden proportionately and all have equal opportunities to share in the products of the research, so that whole industries can advance to positions of stability in the forefront of world technical ability.

The consumer, since he is far down the chain, may not be aware that he benefits so extensively from the labours of the scientists and when the consumer is the foreign customer this lack of awareness may lead to a lack of appreciation of the values offered him in British goods. In publicity for British research, industry has a ready made and potent advertising medium This has already been exploited to great effect by Germany who, before the war of 1914, had largely convinced the world that her products were the best because her research was the most advanced, and with similar persistence America is now engaged in the same process. Products backed by research and advertised as such command world markets.

Publicity for Co-operative Research

What can and should be done in this direction to increase the flow of British goods abroad can also be done to bring home to the domestic consumer his responsibilities to the country's research effort. All this is encompassed by the term public relations. Great departments of State, public bodies and large corporations do not despise public relations. The Post Office, the B B C., banks and large firms spend lavishly to ensure good relations through efficient publicity, but research unwisely stands aloof. This does not imply glamorizing research. It is not a Hollywood bowdlerism but a straightforward story of needs well met and jobs well done backed by evidence in the shape of new products, new machines and new processes that will bring about the realization of everyman's dependence upon a successful research economy.

Improved public relations are necessary, not only because of the needs of research which must be appreciated before they are likely to be met, but because research is going to play an increasing part in the social, economic and political future and it must be understood to be appreciated. In industry there must be technical men who can establish a liaison with central co-operative laboratories to see that the last ounce of value is extracted from their fundamental work to the benefit of every industrial unit Too much research effort now wastes its sweetness on worse than desert air. We have in this country a great tradition of science. We are behind none and before most in our fundamental studies. We have given to the world more than our share of scientific

discoveries, but it is the world outside our islands that has more often benefited than ourselves and the reason is largely that the laboratories are so far ahead of the industries that the significance of their results goes unrecognized. The technical liaison man is a necessity for the future.

It cannot be emphasized too strongly that whether we are thinking of industry or government or the proverbial man in the street it is understanding that is needed. Research does not need charity, it can pay its way handsomely, nor does it need patronage, it can stand alone without difficulty. But it does need understanding. To-day, more than ever, this need is paramount. Never was there so great and probably so temporary an enthusiasm for research. Lip-service without appreciation is the order of the day. Without understanding there can be no effective appeal on behalf of co-operative research nor any of that security of continuity upon which alone it can flourish.

Co-operative Research in Relation to Present National Needs

Never was there such a demand for an intensive build-up of export trade and never was the way clearer to attain it. It is by research and more research piled on to research and the results developed to the limit and applied with all the vigour of which the country, its scientists and its industrialists are capable This is what the Department of Overseas Trade has to say about it [1] "While it is perhaps true that as many fundamental scientific discoveries are made in the United Kingdom as in the United States, it is indisputable that the elaboration and commercial application of basic inventions and developments are carried on far more intensively in the United States. As one factor contributing to the expansion of United Kingdom exports not only to the United States but to all markets, the importance of more intensive industrial research in the United Kingdom cannot be sufficiently emphasized. It is, however, of particular importance in relation to the United States markets precisely because the possibilities of expansion of the United Kingdom's traditional exports are limited, even if such possibilities be fully exploited; it therefore seems essential to develop a new range of exports, based probably upon recent inventions, in order to tap new areas of potential sales"

The needs of the times, of which export is only one, are the measure of the need for co-operative research in Great Britain. We cannot afford to be behind other nations. Our dense population cannot acquiesce indefinitely in a wartime economy nor in a depressed and depressing standard of living. Research is no panacea for our present difficulties but it comes nearer to it than any other effort that we may be able to put forward. Financial jugglery—depreciation of sterling, blocked accounts, tariffs, bilateral agreements, hidden or overt subsidies

[1] Review of Commercial Conditions in the United States of America. H.M.S.O. 1944

—is ephemeral in its effects. Only upon patient, painstaking and unremitting research can any real expectation of success be based, and only then if the research is carefully planned, well organized, adequately financed and intensively applied to the point of commercial exploitation. The war was won as much by the superiority of Allied scientists working co-operatively and to a defined plan, as by the strategy of generals or the heroism of men and women in the Services. The peace will be won in the same way. Just as the Services needed the scientists and the scientists needed the Services so industry and commerce need research, but research without industry and commerce is valueless. On the calibre of our research work in the next few years and the avidity with which it is taken up by industry depends the issue of whether Great Britain is to be a first class or a third class power in the future. The issue is as serious and as direct as that, and in it the co-operative method in industrial research can play a vital rôle.

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